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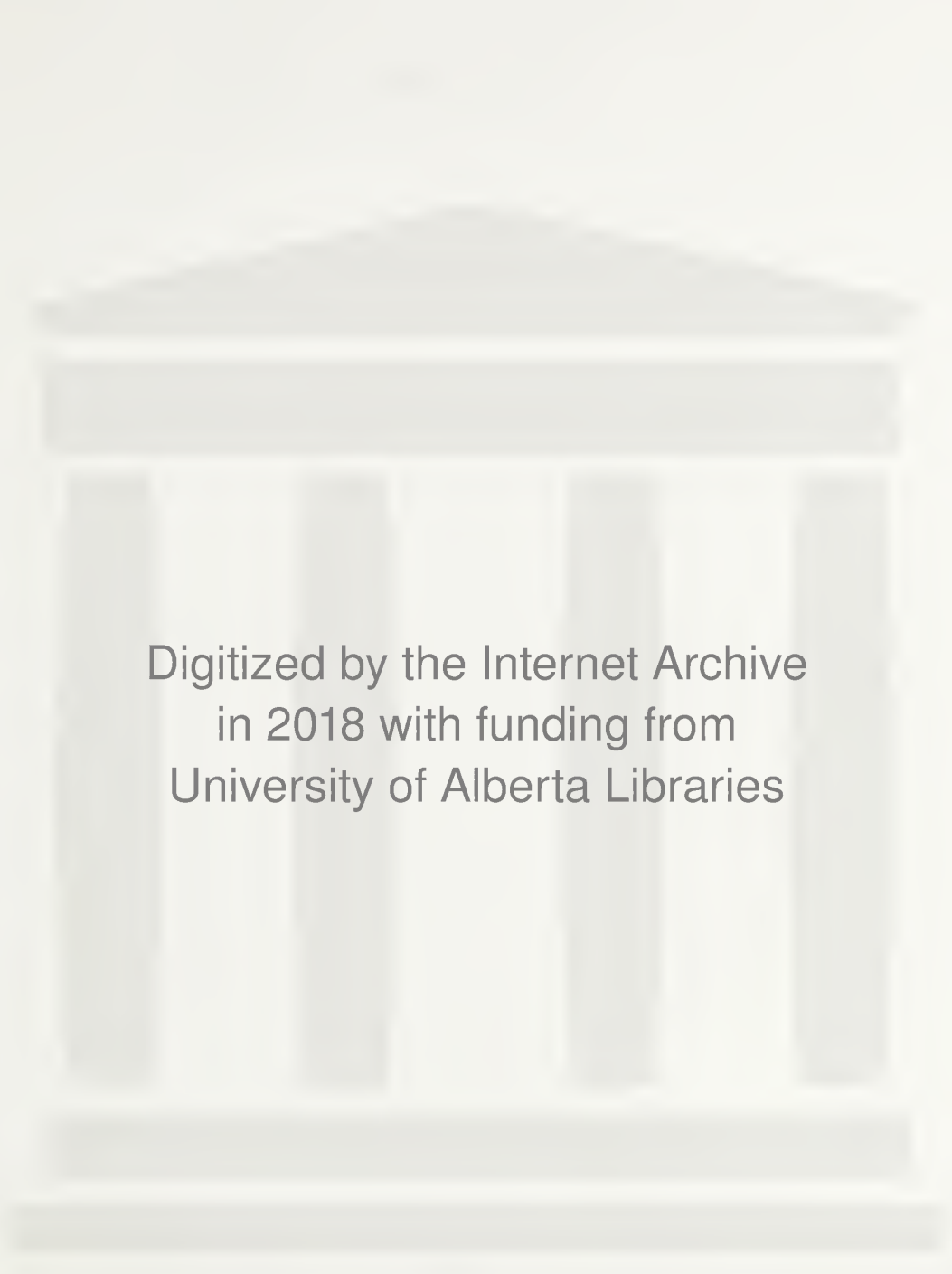
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THE LIMNOLOGY OF THE NORTH SASKATCHEWAN RIVER
NEAR EDMONTON

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
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OF MASTER OF SCIENCE

DEPARTMENT OF ZOOLOGY

EDMONTON, ALBERTA

APRIL, 1966

In Koln, a town of monks and bones,
And pavements fang'd with murderous stones,
And rags, and hags, and hideous wenches;
I counted two and seventy stenchs,
All well defined, and several stinks!
Ye Nymphs that reign o'er sewers and sinks,
The river Rhine, it is well known,
Doth wash your city of Cologne;
But tell me, Nymphs, what power divine
Shall henceforth wash the river Rhine?

Samuel Taylor Coleridge.

ABSTRACT

The limnology of the North Saskatchewan River was studied in the vicinity of Edmonton, Alberta.

The chemistry and physics of the river upstream from Edmonton are modified by season and flow. Turbidity, phosphates and chlorides are directly correlated with flow while most other chemical components show a negative correlation.

The wastes added at Edmonton have an effect on the physics, chemistry and biology of the river. There is an increase in most chemical and physical measures. Stoneflies, mayflies and caddis flies are reduced or absent below effluents while oligochaetes become more abundant. Downstream from the city all organisms become more abundant than in the clean water zone.

The distribution of bottom organisms is more a product of the conditions existing in the substrate than the chemistry of the water.

There is no true planktonic community in the river; the algae being periphytonic forms which are swept into the water column when the water level rises.

ACKNOWLEDGMENTS

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I am indebted to Dr. L. L. Kennedy for identification of the algae and to Dr. G. E. Ball and Dr. H. F. Clifford for examining the aquatic insects. Dr. R. O. Brinkhurst kindly identified the oligochaetes.

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I. INTRODUCTION

Since its founding, the University of Alberta at Edmonton has been located on the banks of the North Saskatchewan River, but despite this close proximity there has not been a limnological study of its waters. The present study had two initial goals; firstly to obtain some knowledge of the physics, chemistry and biology of the natural or 'clean water' river, and secondly to determine what effects the city of Edmonton has on these parameters.

If successful, the attainment of the first goal will provide a background for the pursuit of the many interesting biological problems which a river such as the North Saskatchewan suggests.

The industrial expansion experienced at Edmonton during the last twenty years is likely to continue with a subsequent increase in the numbers and kinds of effluents entering the river. At the same time the methods of waste disposal will be improved so that it is to be expected that the limnology of the river within, and downstream from, Edmonton, will change. The present study will then be useful for comparison.

II. DESCRIPTION OF STUDY AREA

1. General Description:

The North Saskatchewan River rises in the Rocky Mountains along the Alberta-British Columbia border approximately 350 miles west of Edmonton. It flows eastward across Alberta and into Saskatchewan where it meets the South Saskatchewan River to form the Saskatchewan River. The Saskatchewan River enters Lake Winnipeg in the province of Manitoba, the waters of which drain into the Nelson River and ultimately empty into Hudson Bay. In Alberta, the North Saskatchewan River and its tributaries have a total length of 2,200 miles and drain 36,050 square miles, which is approximately 14.1% of the area of the province (Paetz, 1959; Thomas, 1956). By the time the river reaches the city of Edmonton it has drained an area approximately 10,600 square miles.

The river rises at an altitude of 3,180 feet, drops to 2,020 feet at Edmonton and merges with the South Saskatchewan River at an altitude of 1,240 feet. This rather rapid drop, which in the vicinity of Edmonton approaches 1.5 feet per mile, causes the river to be very swift, with an average velocity of 4.5 m.p.h. (Denis and Challies, 1916). The word Saskatchewan is derived from the Cree word meaning rapid water (Burt, 1930).

Eastward from the Alberta foothills the river basin is underlain by Paleozoic and Mesozoic strata covered by glacial drift of considerable depth. Because of this glacial drift,

which is easily eroded, the river flows in a valley characterized by steep banks on the outside of bends, and gravel flood plains on the inside. In the vicinity of Edmonton these flood plains are often extensively used for extraction of gravel.

2. Substrate:

The two principal types of substrate in reaches of strong current are gravel and hard-packed sand. Close to shore, below high embankments, the bottom is often composed of very hard clay nodules. Where there is a slack current the bottom is often composed of fine, soft sand or mud. As will be shown in the discussion of bottom fauna the distribution of substrate type has a marked influence on the numbers and types of organisms found in a given area.

3. Tributaries:

The only tributaries of any consequence entering the North Saskatchewan River within the area encompassed by the study are Whitemud Creek, which is shown in Fig. 1 and the Sturgeon River which is 40 miles further downstream. Except for a short time in the early spring, there is little contribution to the river flow from these sources. During the summer both tributaries are nearly dry except in years of heavy rainfall such as 1965.

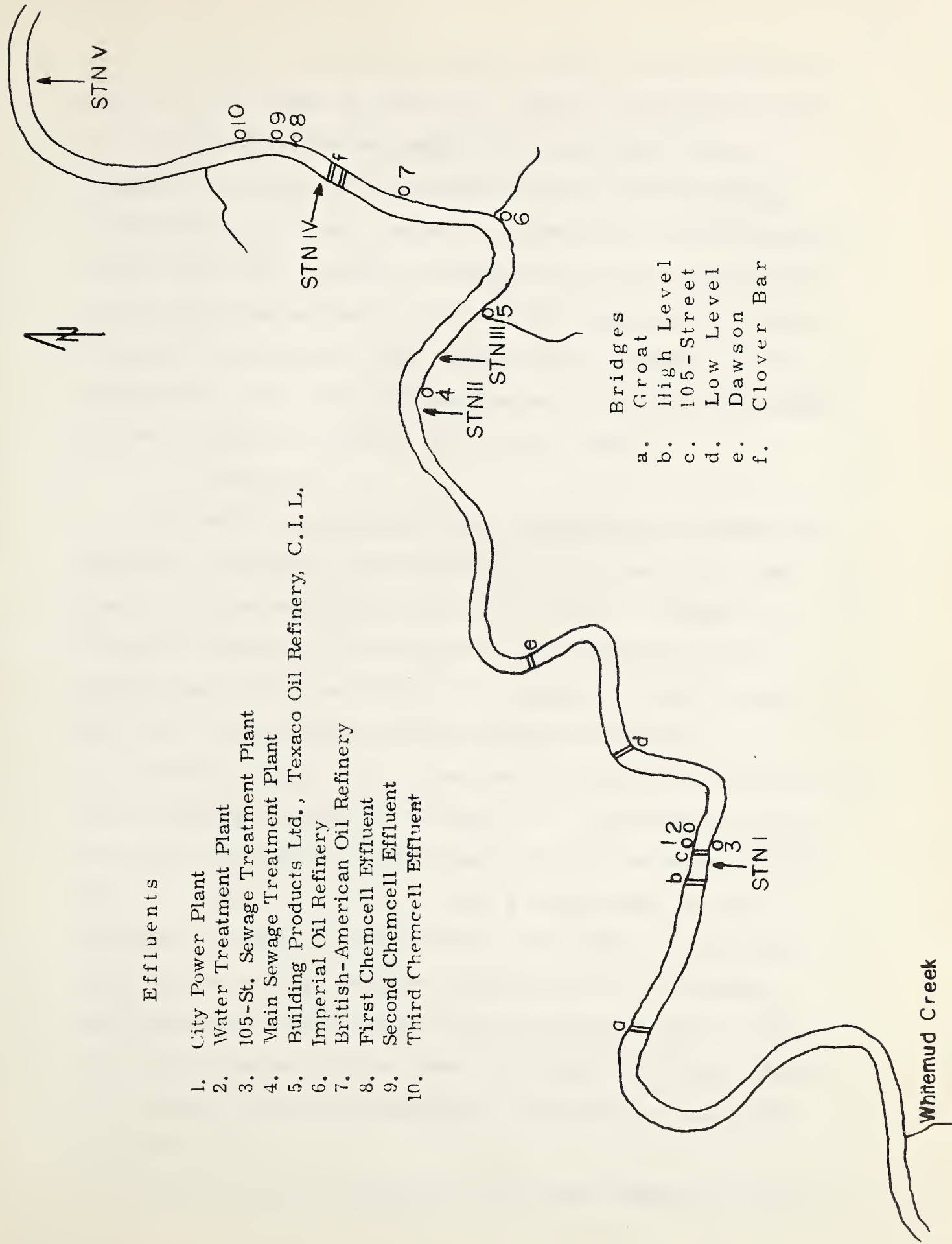
4. Climate:

The climate in the vicinity of Edmonton is listed as being cold temperate. The average winter temperature is 13.7°F and in summer there are few days when the maximum temperature exceeds 80°F. The average annual precipitation

Figure 1. The North Saskatchewan River Study Area

Effluents

1. City Power Plant
2. Water Treatment Plant
3. 105-St. Sewage Treatment Plant
4. Main Sewage Treatment Plant
5. Building Products Ltd., Texaco Oil Refinery, C.I.L.
6. Imperial Oil Refinery
7. British-American Oil Refinery
8. First Chemcell Effluent
9. Second Chemcell Effluent
10. Third Chemcell Effluent



is 18.3 inches of which 71% falls as rain. The average snow fall is 53.8 inches at Edmonton. However the greater depths of snow found in the region of the head waters are most important as they are responsible for the extreme annual fluctuations in flow. During the winter of 1963-64 (October-March) the total snowfall at Edmonton was 34.9 inches while during the same period in 1964-65, 75.2 inches fell as snow. From April to October, 1964 there was 12.5 inches of rain as compared to 16.4 inches during the period April to September of 1965 (Dom. Pub. Weather Off., pers. comm).

5. Ice Cover:

The North Saskatchewan River, immediately upstream from Edmonton, is usually ice-covered for 4-1/2 months of the year, with ice beginning to form as early as November 1. Complete coverage is not realized until December, with breakup most often occurring in mid-April. Table I lists the annual breakup date for the period 1920-1965.

In the spring of 1964 when the present study was initiated, the ice began to break up on April 21. On November 6 of the same year there was no ice present, but by November 25 there was ice floating on the river and a solid sheet of ice extended out approximately 25 feet from shore. This shore-attached ice slowly extended outwards until by December 2 there remained only an open channel approximately 50 feet wide. By December 23 the river was completely frozen wherever natural conditions prevailed. In 1965 the ice broke up on April 23.

Within the city proper the city power plant and many of

Table I. Breakup Dates of the North Saskatchewan River
at Edmonton.

<u>Year</u>	<u>Date</u>	<u>Year</u>	<u>Date</u>
1920	April 29	1943	April 10
1921	15	1944	5
1923	19	1945	19
1925	8	1946	8
1926	14	1947	12
1927	18	1948	24
1928	26	1949	11
1929	25	1950	18
1930	4	1951	13
1931	16	1952	10
1932	14	1953	24
1933	23	1954	May 5
1934	11	1955	April 10
1935	20	1956	13
1936	15	1957	17
1937	15	1961	13
1939	12	1962	16
1940	17	1963	14
1941	8	1964	21
1942	17	1965	23

the industries release cooling waters or industrial wastes which are at temperatures well above that of the river during the winter. This causes an open channel to be maintained for 11.5 miles downstream throughout the winter. The open channel starts at the city power plant at Station I and extends slightly below Station IV.

6. Flow:

Denis and Challies (1916) note that the chief characteristic of rivers rising in the Rocky Mountains is the extreme variation between maximum and minimum flows. They report the ratio between maximum and minimum flow to be as great as 200:1. The ratio of greatest recorded maximum (204,500 c.f.s. June 28, 1915) and lowest recorded minimum (220 c.f.s. January 1, 1940) in the North Saskatchewan River at Edmonton is in the neighborhood of 930:1, although the ratio in any given year does not approach this value.

Because flow in the river is controlled by the climate in the Rocky Mountains, it is found that very rapid changes in flow often occur. The flow, as expressed in cubic feet per second (c.f.s.), may double from one day to the next and changes in flow of 10,000 c.f.s. over a period of 24 hours are not uncommon. Fig. 2 shows Station I at high water and Fig. 3 shows the same site at low water.

Fig. 4 presents the average monthly maximum, minimum and mean flows for the period 1920-1960, while Fig. 5 shows the same measures for the period 1961-1964. The latter figure illustrates the increase in winter flow rates since 1961. At this time the Brazeau River Dam, located on a major tributary



Figure 2. Station I at high water (June, 1964).



Figure 3. Station I at low water (August, 1964).

Figure 4. Average monthly flow, 1920-1960.

FLOW
c.f.s. $\times 10^{-3}$

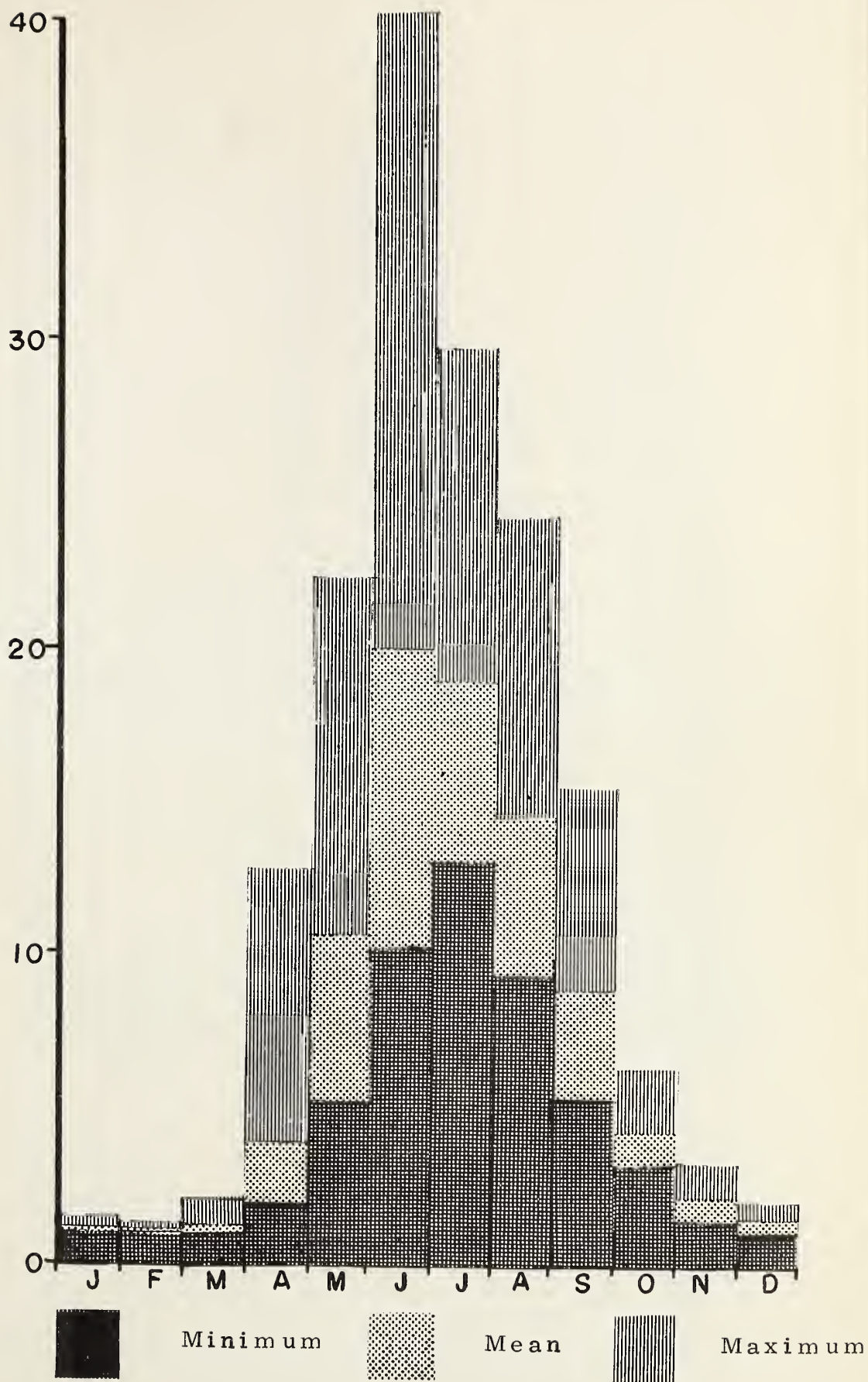
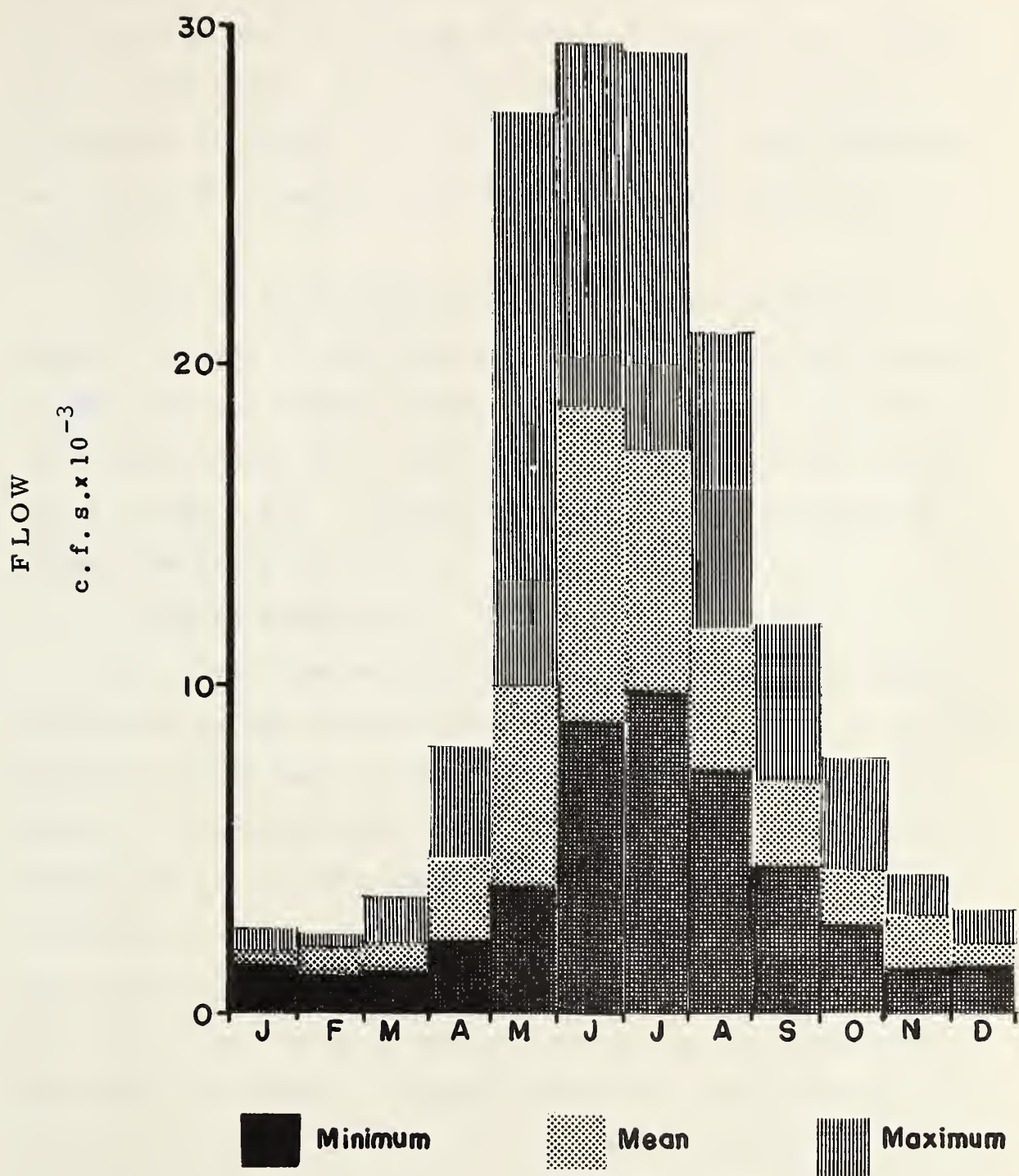


Figure 5. Average monthly flow, 1961-1964.



of the North Saskatchewan River upstream from Edmonton, came into operation. The dam is essentially a hydro-electric installation but it is also utilized to increase the winter flow in the river. It is hoped that winter flow may be stabilized in excess of 1,500 c.f.s. so that more industrial wastes may be released into the river during the winter months.

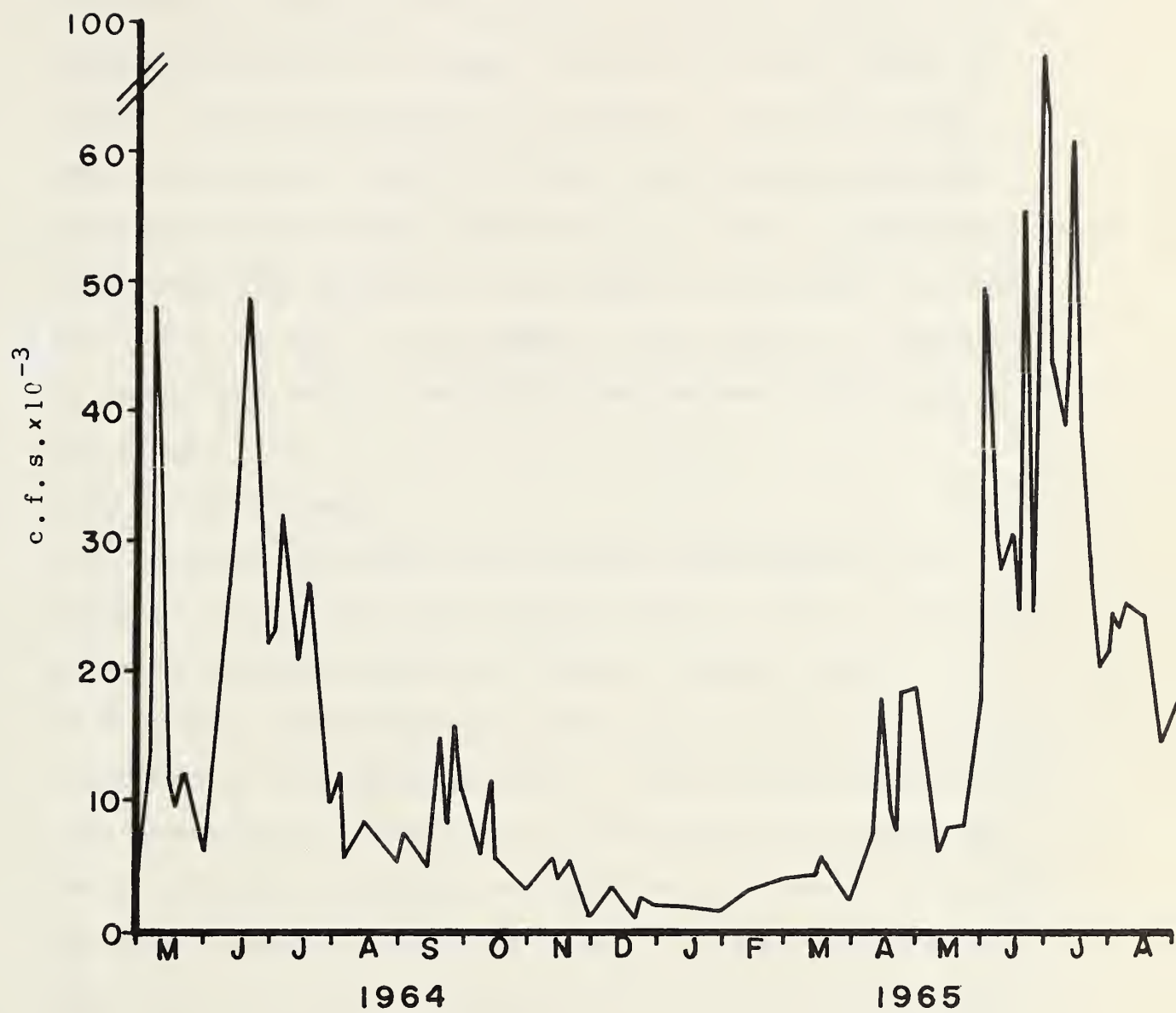
As can be seen from Figs. 4 and 5 there has been a slight increase in the minimum and a more noticeable increase in the mean and maximum winter flows since 1960. The reduced June maximum flow from 1961-1964 was a result of the greater flows in May. Fig. 6 shows the flows recorded at Edmonton during the study period.

7. Width and Depth:

In a river such as the North Saskatchewan which experiences such marked fluctuations in flow, expressions of average width and depth have little meaning. Expressions of variability, such as maximum and minimum values, are of more value. During the period 1960-1964, the river showed annual flow fluctuations which are in close approximation to the long term averages. During this period the width of the river in the study area varied between a minimum of 100 yards and a maximum of 300 yards. Although there was some variation in width at any given time, it was very small in relation to the variation in width due to flow differences. Where the river has high steep banks, a vertical rise or fall in water level caused little extension in submerged or exposed areas. Where the river flowed over gravel and sand reaches with a

Figure 6. Flow in the North Saskatchewan River at
Station I during the study period.

FLOW



shallow slope a rise of a few inches in water level would increase the river width by several yards.

As the river width within the study area showed some variation and as the substrate varied as to the ease with which it could be shifted by the current, there was found to be a marked irregularity in depth. During low water levels of autumn, the maximum depth of a transect across the river may vary from two feet to 17 feet. The maximum variation in water level has been found to be 38.5 feet (Canada Dept. Natural Resources, 1962). Because of the marked fluctuations in width and depth, as well as the speed of the current, no emergent or submergent aquatic vegetation has become established in the river.

8. River Uses:

Although the basin of the North Saskatchewan River occupies only 14.1% of the area of Alberta, this is the area with the greatest population density (Thomas, 1956). It is estimated that 45% of the total population of the province lives within this drainage basin. Upstream from Edmonton the only communities of any size on the banks of the river are Devon, 20 miles upstream, and Rocky Mountain House, 300 miles upstream. Except perhaps for some oil wastes released into the river at Devon and Drayton Valley, there was no observable effect of upstream communities on the river by the time the water had reached Edmonton. For the purposes of this study the river immediately upstream from Edmonton was considered to represent the natural clean water condition.

With the development of the oil and natural gas resources

near Edmonton in the early 1950's the city has experienced both a population and an industrial boom. The city has a population of 390,000 (1964) which utilizes the river as a domestic water source and as a means of disposing of treated sewage. The industrial complex, which uses the river as a source of cooling and process water as well as a means of disposing of wastes, is largely concentrated on the eastern edge of the city. These industries either are directly connected with the petroleum industry or are attracted to the area by the accessibility of natural gas as a fuel. Table II lists the major industries which release effluents directly into the river. Most other industries in the city pass their waste products into the city sewage system. Fig. 7 and Fig. 8 show one of the effluents from Chemcell Ltd. and one of the refinery effluents respectively.

In the winter the frozen river is used as a dumping ground for snow removed from city streets (Fig. 9).

Domestic sewage is treated at two sewage treatment plants. The smallest of these is located on the south bank of the river at the 105 St. bridge. This plant, which offers only primary treatment, treats 2.5 million gallons per day and the sewage which it receives is from an entirely residential area. The main treatment plant is located on the south bank at 50 St. and receives 20 million gallons per day. This plant has a secondary treatment process which is put into operation during the winter months when the river is at a low level and ice covered. Table III lists the average analysis of the

Table II. Edmonton Industries Disposing of Wastes Directly Into the North
 Saskatchewan River.

<u>Industry</u>	<u>Year Started</u>	<u>Waste Products</u>
British American Oil Refinery	1951	Phenols, oils
Building Products Ltd.	1951	Paper pulp
Canadian Industries Ltd.	1953	Phenols, oils, chromates
Chemcell (1963) Ltd. (Canadian Chemical Co.)	1953	Formaldehyde, cellulose acetate, High B.O.D. wash water
Imperial Oil Refinery	1948	Phenols, oils
McColl Frontenac Oil Refinery	1951	Phenols, oils
Texaco Oil Refinery	1951	Phenols, oils



Figure 7. Third Chemcell Ltd. effluent.



Figure 8. Oil refinery effluent.



Figure 9. Snow dump on the North Saskatchewan River at Edmonton.



Figure 10. Main sewage treatment plant effluent.

Table III. Average Effluent Analysis of the Main
Sewage Treatment Plant.

Temperature	18.3 C.
pH	7.1
Grease	10.0 p.p.m.
Phenols	16.0 p.p.b.
Total nitrogen	26.4 p.p.m.
Organic nitrogen	1.2 p.p.m.
Nitrates	15.0 p.p.m.
Nitrites	1.2 p.p.m.
Synthetic detergents	3.3 p.p.m.
Biochemical oxygen demand	35.0 p.p.m.

effluent from this plant. Fig. 10 shows this effluent.

As the city storm sewers also drain into the main plant it is possible that during heavy rains more water and sewage will enter the plant than can be properly treated. This results in a sewage effluent which has a higher biological oxygen demand (B.O.D.) than the normal effluent.

There is one small sewer on the north side of the river upstream from the Low Level Bridge which releases raw sewage into the river but the total volume of this sewage is very small. Fig. 1 shows the points of entry of the main domestic and industrial effluents into the river.

Prior to the building of the railroads in the vicinity of Edmonton in the early 1900's the river was used by barges for the transport of freight to and from Edmonton. From 1900 until 1962 the river was used very little as a waterway for commercial or pleasure boating. In the summer of 1963 interest in boating on the river was revived and in the summer of 1964 there were two commercial excursion boat establishments and numerous private craft plying the river.

The North Saskatchewan River, in the vicinity of Edmonton, is not extensively fished. Although there is some sports fishing along the river, angling is most concentrated at the mouths of Whitemud Creek and the Sturgeon River. There is no commercial fishing in the river in Alberta.

III. PAST STUDIES

Prior to the population and industrial boom experienced by the city in the late 1940's, the load of waste material released into the North Saskatchewan River probably had a negligible effect. However, when the Public Health Department of the Province of Alberta began chemical and bacteriological examination of the river in the winter of 1950-1951, it found that the river below Edmonton, especially when ice-covered, was polluted. Following the classification of pollution based on B.O.D. as proposed by Hynes (1960), the river at Station IV-S would fall into a badly polluted category since the B.O.D. was above 5 p.p.m. As the water passed downstream the B.O.D. was increasingly satisfied but the oxygen so used, in the winter, decreased the dissolved oxygen (D.O.). At Lloydminster the D.O. often fell below 1 p.p.m. for several weeks on end.

Atton (1954) reported that in the winter of 1953-1954 there was 1 p.p.m. or less dissolved oxygen in the river from the town of Two Hills, which is 117 miles downstream, to the confluence with the South Saskatchewan River. At the same time the D.O. at Station I and other points upstream from it averaged 9.7 p.p.m. Many dead fish were observed by Atton in the vicinity of Prince Albert, Saskatchewan, and a 70-yard gill net set under the ice for 12 days failed to produce any living fish. Living burbot (Lota lota), chub (Hybopsis sp.), and suckers (Catostomus sp.) were placed in wire baskets under the ice. Distress reactions were displayed within a few minutes with death following in less than five

hours for the burbot and chub. The suckers managed to survive for nearly two days before succumbing. The oxygen concentration at the site of this testing was 1 p.p.m.

During the interval 1958-1960 the Alberta Public Health Department placed stringent restrictions on the waste waters which could be released into the river. Owing to this the D.O. remaining under the ice at Lloydminster rarely drops below 4 p.p.m. and the classification of the river on the basis of B.O.D. at Station IV is one of only slight pollution.

From an examination of chloride concentrations in the river between 1950 and 1964 it is obvious that Edmonton has an effect on the concentration of this ion. Immediately downstream from the city the river contained more chloride than above the city. Chloride is a stable ion and no noticeable variation occurred with the passage of the water downstream. The Western Chemical Co. at Duvernay, which manufactures hydrochloric acid, and the Canadian Salt Co. establishment between Elk Point and Lloydminster, release effluents which increase the chloride content of the river by an additional factor of three or four. On occasion the chloride content of the river at Duvernay may exceed 1,000 p.p.m. It is possible that concentrations of this magnitude may be deleterious to aquatic organisms but no data are available from the river. Since the winter of 1961-1962 there has been a decrease in the chloride added at Duvernay but the chloride added at Edmonton has remained relatively constant.

Since the restrictions were placed on the effluents which could be released, there has been a drop in the concentrations

of oils and phenols found in the river below Edmonton. Prior to 1958 concentrations of phenols as high as 120 p.p.b. were found but since then winter concentrations much in excess of 15 p.p.b. are rare. At present the government allows each of the five industries producing phenolic wastes to release 3.5 pounds of concentrated waste each day for every 1,000 c.f.s of flow. Many of the industries either store phenolic wastes for release during the high summer flows or pump them down negative pressure wells. As oil is not a waste product, most industries attempt to trap and separate it from their effluent so that oil pollution is not a major problem in the river.

The Public Health Department has collected data since 1950-1951 on the alkalinity and pH of the river from above Edmonton to the Saskatchewan border. These data do not show any marked effect of the city on either parameter. Spot determinations of other components were carried out at various sites on the river but these data are not extensive enough to allow extraction of any general conclusions.

There are reports of several cases of typhoid fever occurring in the period 1950-1951 as a result of drinking untreated river water upstream from Edmonton. Perhaps due to the more complete sewage treatment effected at Devon this occurrence has become rare. One case, however, was reported in the summer of 1964 (Alta.Dept.Public Health,pers.comm.).

The limited amount of fishing in the North Saskatchewan River does not warrant particular attention. However, it is interesting to note that the Public Health Department has

received reports of an oily taste in fish caught downstream from Edmonton. This taste was first noted soon after the commencement of oil refining operations at Edmonton. Sufficient data are lacking on taste problems but indications are that oil or phenol wastes, even though present in small quantities, are responsible.

Perhaps some of the distributional peculiarities exhibited by certain organisms in the river, as will be discussed later, may be explained in terms of conditions prevailing in the river prior to 1958 rather than to the present conditions.

IV. MATERIALS AND METHODS

1. Organization:

Collection of physical and chemical data for this study began in mid-May of 1964 and terminated at the end of August of 1965. Some biological sampling, especially of fish, was done prior to 1964. For the purpose of sampling the river, six stations were established as shown in Fig. 1. The distance of each station below the mouth of Whitemud Creek is given in the following table.

Table IV. Station Locations.

Station	Distance downstream from Whitemud Creek (miles)
I	4.8
II	9.9
III	10.6
IV	13.1
V	16.0
VI	37.4

Each station was originally sampled at midstream but as the river has a rapid flow it was found that total mixing of any effluent with the river water did not occur until some distance downstream from its point of entry. For this reason sampling was begun at a point near both the north and south shore at each station. Thus in the text a station number followed by the letter 'N' refers to the station near the north shore and if followed by the letter 'S' indicates that the

the sample was obtained near the south shore. A numbered station without a shore designation refers to the average of the two shore samples or to the midstream sample.

During the ice-free period, whenever possible, Stations I-V were visited once a week by boat and Station VI was visited semi-monthly by vehicle. When the river was extremely high or when ice conditions prevented the use of a boat, only Stations, I, II, V, and VI were visited as Stations III and IV are not accessible by road.

When this study was initiated another station was established 0.9 miles above the mouth of Whitemud Creek. Although there are a few storm sewers entering the river between this point and Station I, the two stations were found to be almost identical and thus this site was abandoned for the purpose of systematic physical and chemical sampling.

2. Chemistry and Physics:

At each sampling point water temperature and conductivity were measured with a Whitney Thermistor. Unfortunately a conductivity meter was available only during the 1964 segment of the study. Three 150 ml. ground glass stoppered bottles were filled, one of which was immediately fixed for an unmodified Winkler method oxygen determination. The actual titration to determine dissolved oxygen (D.O.) was done within a few hours in the laboratory. The other two samples were used for 5-day B.O.D. determinations. Originally a Kemmerer water bottle was used to collect all water samples but it was found that the turbulence created by simply immersing the sample bottle did not cause a gain of any measurable amount

of oxygen. This is because the river water was nearly saturated with oxygen at all times. The Miller method (Miller, 1914) of oxygen determination was also tried but it was found that the high turbidity of the river water, especially in the spring, obscured the endpoint determination to a degree which prompted abandonment of this method.

Initially a 20°C water bath was not available so the B.O.D. samples were stored at room temperature in a dark drawer for 5 days. The room temperature in the laboratory varied between a low of 21°C and a high of 29°C. From October, 1964 until the end of the study, the bottles were held in a 20°C water bath. It was found that no great difference in B.O.D. occurred when both methods of storage were used on identical samples. At the end of the 5-day period the dissolved oxygen remaining in the sample was determined using the Winkler method. In certain reaches of the river the B.O.D. of the water was greater than the amount of oxygen originally present. In these cases the sample was diluted with distilled water and an original and 5-day D.O. determined for the diluted sample. It was found that a 5-day sample of distilled water did not utilize any oxygen.

A one-litre bottle was filled with water and was later used in the laboratory for chemical analysis and originally for the determination of suspended and dissolved solids. All chemical analyses were made using a Hach Direct Reading portable water analysis outfit. Throughout the summer of 1964 periodic samples were sent to the Alberta Provincial analyst as a check against my own results. It was found that

the methods used gave results which corresponded very well with those determined by the provincial analyst. Analyses were usually carried out on the day of collection, but if this was not possible the samples were refrigerated until the next day.

For the determination of total solids, two 25 ml. samples were pipetted into dry tared crucibles and then evaporated at 100°C and reweighed. The crucibles were then placed in an oven at 500°C for one hour, cooled in a desiccator, and weighed. From this the percentage of fixed and volatile material could be determined. Although these are often referred to as the inorganic and organic components respectively, it has been found that this is not strictly true as there is a loss of carbon dioxide from the bicarbonate ion and a loss of chloride upon ignition (Hutchinson, 1957). The procedure for the determination of total dissolved solids (T.D.S.) was identical except that the water sample was passed through two thicknesses of Whatman #1 filter paper. When the total sum of constituents was determined from chemical analysis it was found that this value exceeded the T.D.S. by as much as 100%. This was a result of the reduction of the bicarbonate ion which is the major anion in the river water. As the loss was not constant the T.D.S. could not be corrected and thus these data could not be utilized.

Starting in the early spring of 1965 a 100 ml. sample of water was passed through a weighed piece of 5μ Millipore filter paper. This was then dried in a desiccator at room temperature and reweighed to yield an approximation of the

total suspended solids. Although some suspended material less than 5 μ in diameter passed through the paper its weight was negligible. If a paper of smaller pore size was used it plugged so rapidly that 100 ml. of water could not be filtered.

A Hellige pocket comparator using phenol red D as an indicator was initially used to determine pH. It was found that no change in pH occurred when a water sample was taken to the laboratory and retested. As a Beckman glass electrode -pH meter is more accurate it was extensively used after the late summer of 1964 to determine the pH of samples brought into the laboratory. This was an attempt to detect any small changes which might occur as a result of the addition of industrial wastes to the river.

3. Substrate Analyses:

Several mud and sand samples were taken with an Ekman dredge from each station. All samples from one station were mixed together and the composite divided into two fractions. One of these was sent to the Soil Testing Laboratory at the University of Alberta for chemical analysis. The other was used to determine percent organic material in the following manner. A level tablespoon of mud was put into each of two dry tared crucibles. These were then dried at 100°C, cooled and weighed, and then ignited at 600°C for one hour. They were again weighed and the percent volatile material calculated from the average of the two samples.

4. Plankton:

River plankton was initially sampled by passing 18 litres

of water through a large Wisconsin plankton net of number 25 bolting silk. This was carried out at each station whenever limnological data were collected. The concentrated sample was washed from the plankton bucket into a vial with distilled water and then preserved with 40% isopropyl alcohol. This is not as good a fixative as formaldehyde but was found suitable for this purpose. The plankton in each sample was counted by mixing the sample well and then placing one ml. in each of two counting cells. One quarter of each cell was examined under a monocular microscope using low power (100X) and the calculated number in the two cells averaged to yield the numbers per milliliter. By measuring the volume of the preserved sample it was then possible to calculate the number of plankters per litre of river water.

The samples contained large quantities of non-living material being transported by the river current which could not readily be separated from the plankton. Because of this no attempt was made to determine the weight of the plankton.

Certain of the easily recognized forms, such as Stigeoclonium, Pediastrum and Asterionella, were recorded separately, but most other forms were recorded only to phylum.

This method, though commonly utilized in the study of lotic environments, was deemed unsuitable for determining what effect, if any, the city has on the flora of the river for reasons to be explained later. Instead, during the early summer of 1964, several rocks of 3 or 4-inch diameter were collected at each station. An approximate equal volume of rocks from each sampling site were then washed clean in one

litre of distilled water. This suspension was examined in the manner previously described for plankton.

5. Bottom Fauna:

As was previously discussed the substrate of the North Saskatchewan River is mainly composed of mud, sand and gravel. In the reaches having sand or mud bottoms a six-inch square Ekman dredge was used to sample the bottom fauna. Due to the speed of the current this type of substrate is often found only in areas where the current is reduced, such as near shore and around the edges of sand bars. It is not possible to use the Ekman dredge where the current is swift, as it will not settle properly on the bottom.

The sample of substrate obtained with the dredge was placed in a pail and later washed through two screens of diminishing size. The uppermost screen had 17 meshes per linear inch and the lower 45 meshes per inch. The depth at which the sample was obtained, the nature of the substrate, and the type and quantity of detritus were recorded. All living organisms found on the screens were preserved in 10% formalin. Exuviae of insects or empty gastropod shells were not preserved. The number of each species was counted. The wet weight was determined by weighing on an analytical balance after excess moisture had been removed with filter paper.

Where the river flowed over a gravel and boulder bottom a square-foot Surber sampler was used. This type of substrate, as revealed at low flows, is shown in Fig. 11. All organisms so collected were treated in the same manner as those collected



Figure 11. Gravel and boulder substrate at Station VI exposed during low water.

with the Ekman dredge.

As all samples of bottom fauna were collected near the shore there is the possibility that they are not representative of the fauna of the whole river. Berner (1951) has shown that in the Missouri River the weight of organisms per unit area in mid-stream is only 1/11 of that found near shore. The few samples obtained near the middle of the North Saskatchewan River would indicate that the same tendency prevails there. Therefore, for the purpose of comparing the bottom fauna of different reaches of the river, the richer samples taken near shore are more likely to reveal any differences which may exist.

6. Fish:

The speed of the North Saskatchewan River makes it very difficult to set a gill net and sudden fluctuations in water level are so frequent that there is no assurance of being able to retrieve a net once set. For these reasons most gill nets were set in the mouths of Whitemud Creek, Sturgeon River, or a blind channel of the river at Big Island, 12.2 miles above Station I. As there is no visible barrier to prevent fish from moving into the mouths of these channels, and as at high water the channels are filled with what is essentially river water, the fish so taken were considered to be characteristic of the population existing in the river proper. An attempt was made to float a short net down the river near Station I. The net kept catching on obstructions on the bottom and tearing, so the method was abandoned. All fish taken in the nets, as well as fish taken by angling, were

weighed, measured in fork length, and a scale sample was taken from just above the lateral line in the region immediately in front of the dorsal fin. The sex of each specimen was determined and a cursory examination of stomach contents was made.

Throughout the study area, wherever the depth and nature of the bottom permitted, fish were collected by use of a thirty-foot commonsense seine of 1/4 inch mesh. If the number of fish collected was small, all of them were preserved in 10% formalin, but if large numbers were obtained only a random sample was preserved. The number and length of hauls required to obtain each sample were recorded and notes were made on the depth of water, substrate type and relative efficiency of the seining. From this it was thought that variations in abundance of different species in different parts of the river could be obtained.

Collections of fish were also made by seining in Whitemud Creek and the Sturgeon River.

V. PHYSICAL CHARACTERISTICS

1. Temperature:

a. Seasonal variation:

Fig. 12 shows the annual temperature regime of the river as measured at Station I. The river cooled to a temperature of less than 1°C in late November and stayed at that temperature until shortly before breakup. It then warmed rapidly and reached a maximum which differed during the two summers. The water began to cool during the first week in August. The drop in temperature experienced on July 24, 1964 is thought to have been due to the cooling effect of 0.85 inches of rain which fell in the nine-day period previous to this date, as there are no appreciable differences in mean air temperatures during this same period.

b. Regional variation:

All effluents entering the river in the study area did so at a temperature greater than that of the receiving water. This caused an increase in water temperature as the river passed from Station I to Station V. The increase was not constant, as it depended on the river flow, volume and temperature of effluents, and air temperature. As the effluents took some time to mix completely with the river water the temperature was invariably higher near both shores than in the middle of the river. Because the city power plant was the only heated effluent entering on the north shore, the temperature was higher there only until the water reached Station III; whereupon there was a reversal and the south shore became warmer. Fig. 13 shows the average increase experienced

Figure 12. Seasonal variation in water temperature.

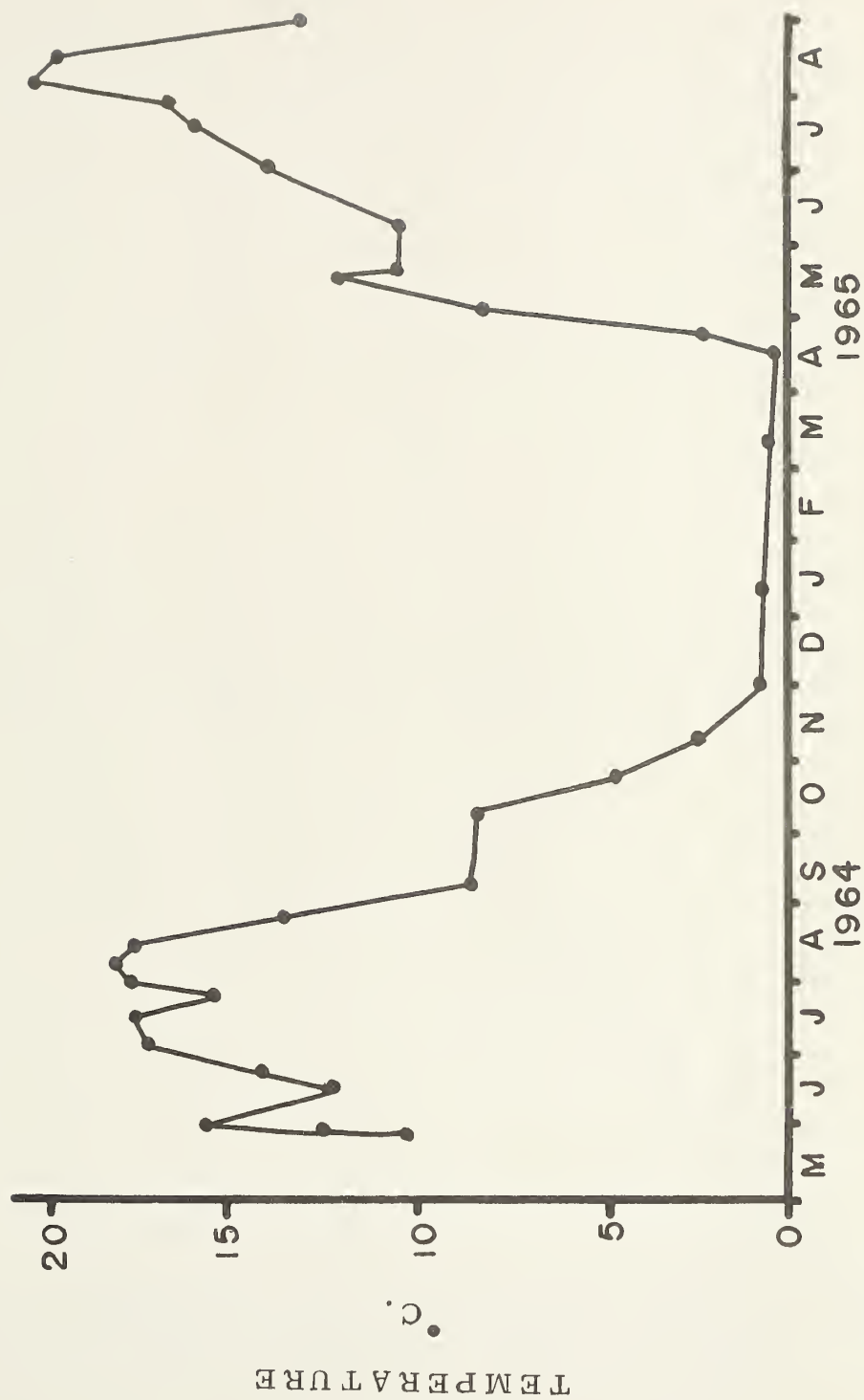
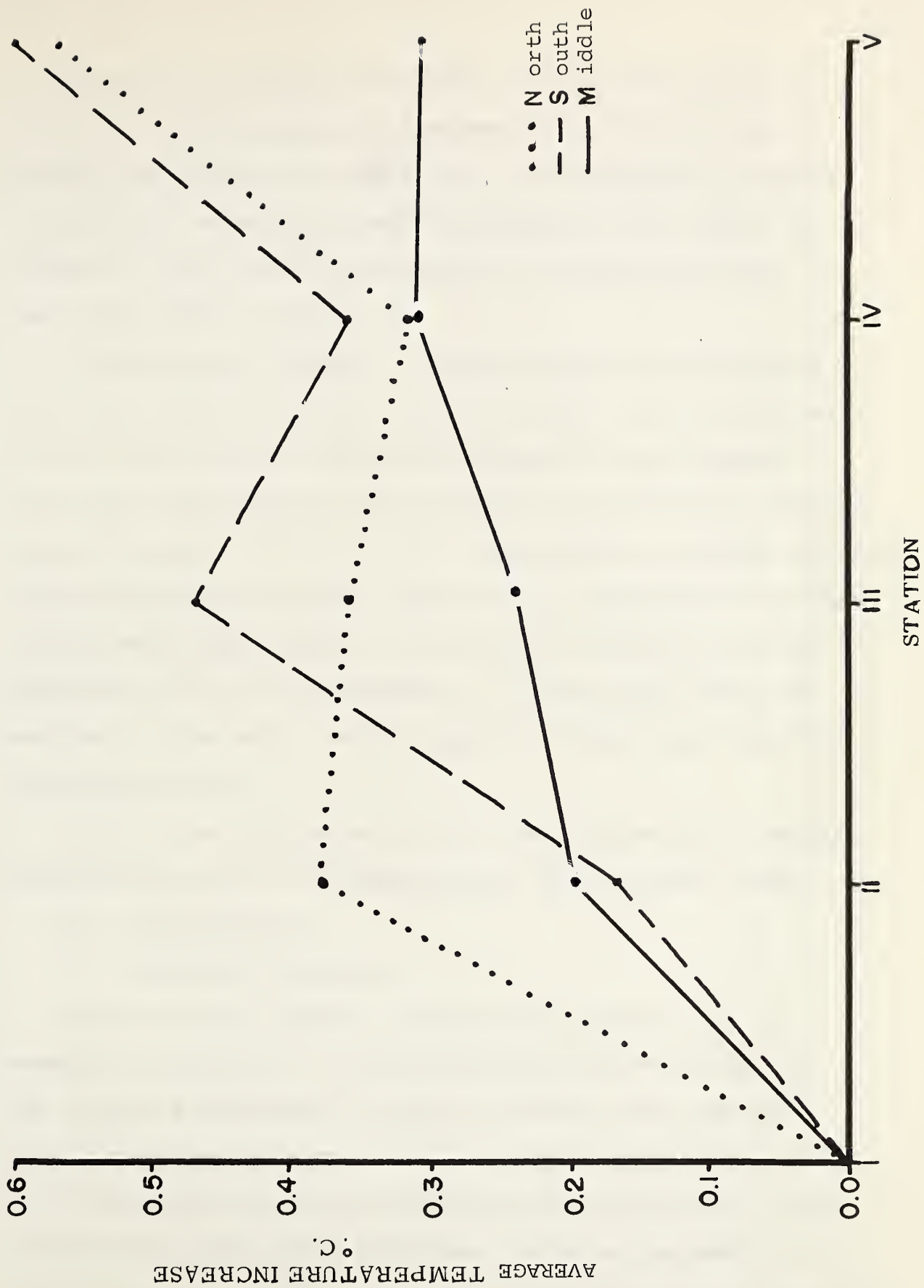


Figure 13. Regional variation in water temperature.



at the various stations throughout the ice free period of the study. The increase in temperature at Station V-N was higher than expected as there was no corresponding increase in the water temperature near the middle of the river. At Station VI the river had returned to a temperature very near that found at Station I.

The absolute increase in temperature shown at Station V was never more than 1.7°C . When the river flow was reduced in the winter months the heated effluents could increase the water temperature by 500%, although the absolute increase was quite small, 0.01 to 0.52°C . The greatest absolute increases occurred during the summer months as air temperature was then usually well above that of the water and little of the heat added was lost to the atmosphere. In the winter the river was open in the region of the heated effluents and thus heat was rapidly lost.

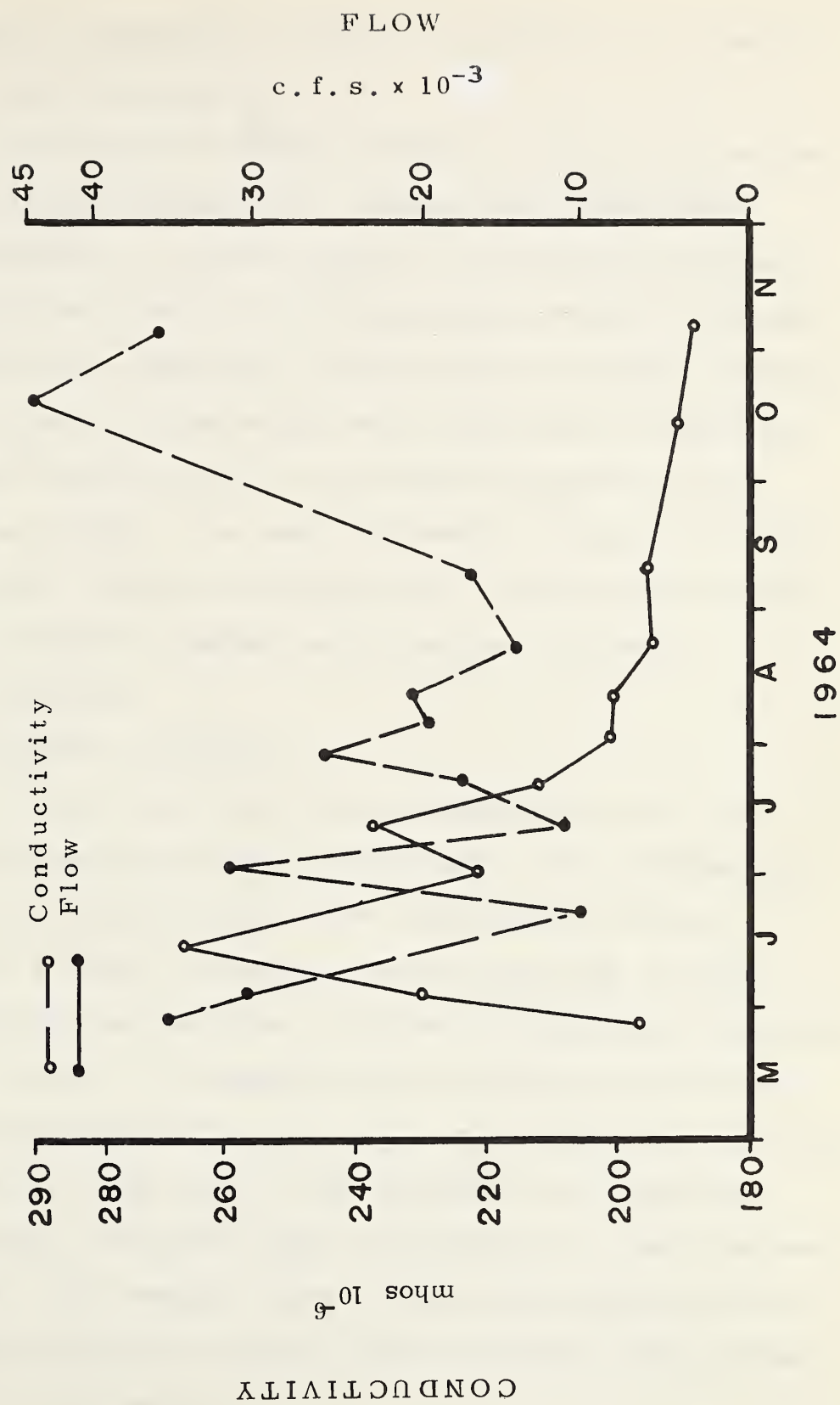
Due to the turbulence of the river, there was no temperature differences at different depths in the water column.

2. Conductivity:

a. Seasonal variation:

The variation found in conductivity during 1964, as measured at Station I, is plotted against flow in Fig. 14. The inverse relationship is due to the fact that the high water in spring and summer was a result of surface run-off which contained only small amounts of dissolved salts. This diluted the ground water which was the major component of the river in winter and which was very rich in dissolved substances. The same inverse relationship will be shown for many of the

Figure 14. Seasonal variation in conductivity.



major chemical components of which conductivity is a measure.

b. Regional variation:

Fig. 15 shows the average change in conductivity at the various stations during 1964. Because the conductivity changed markedly in a short period, the increase at Station VI is only approximate as the measurements at this site were never made on the same day as at the other stations. Readings were not obtained often enough near both shores to show the differences graphically, so the average increase at each transect is figured. The most noticeable increases occurred near the south shore at Stations III - V and are due to the addition of domestic sewage and industrial effluents.

3. Turbidity:

a. Seasonal variation:

Fig. 16 shows that the North Saskatchewan River was very turbid during periods of high flows, with readings approaching 600 Jackson units. The turbidity was almost exclusively a result of surface run-off and bank scouring because during the low flows of winter the turbidity was often less than 5 units. As expected, the turbidity can be almost directly correlated with flow. The small variations found are due to the fact that many of the suspended clay particles were relatively large and their distribution in the river was not uniform. Two samples taken at the same location within a one minute interval, when the flow was great, often showed a variation of 50 units.

The suspended solids, as determined by the use of 5 μ Millipore filter paper, show that the suspended solids, expressed

Figure 15. Regional variation in conductivity.

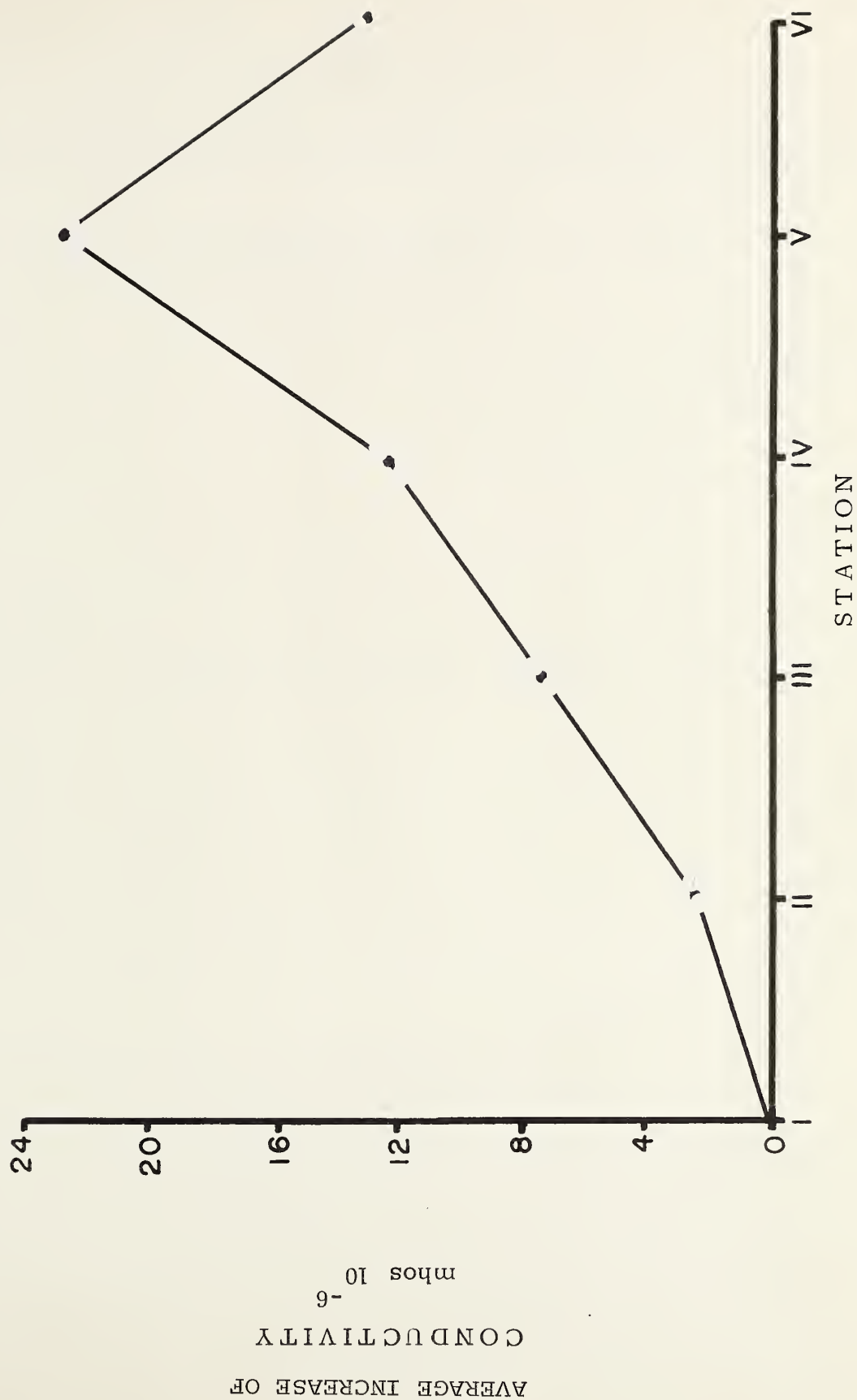
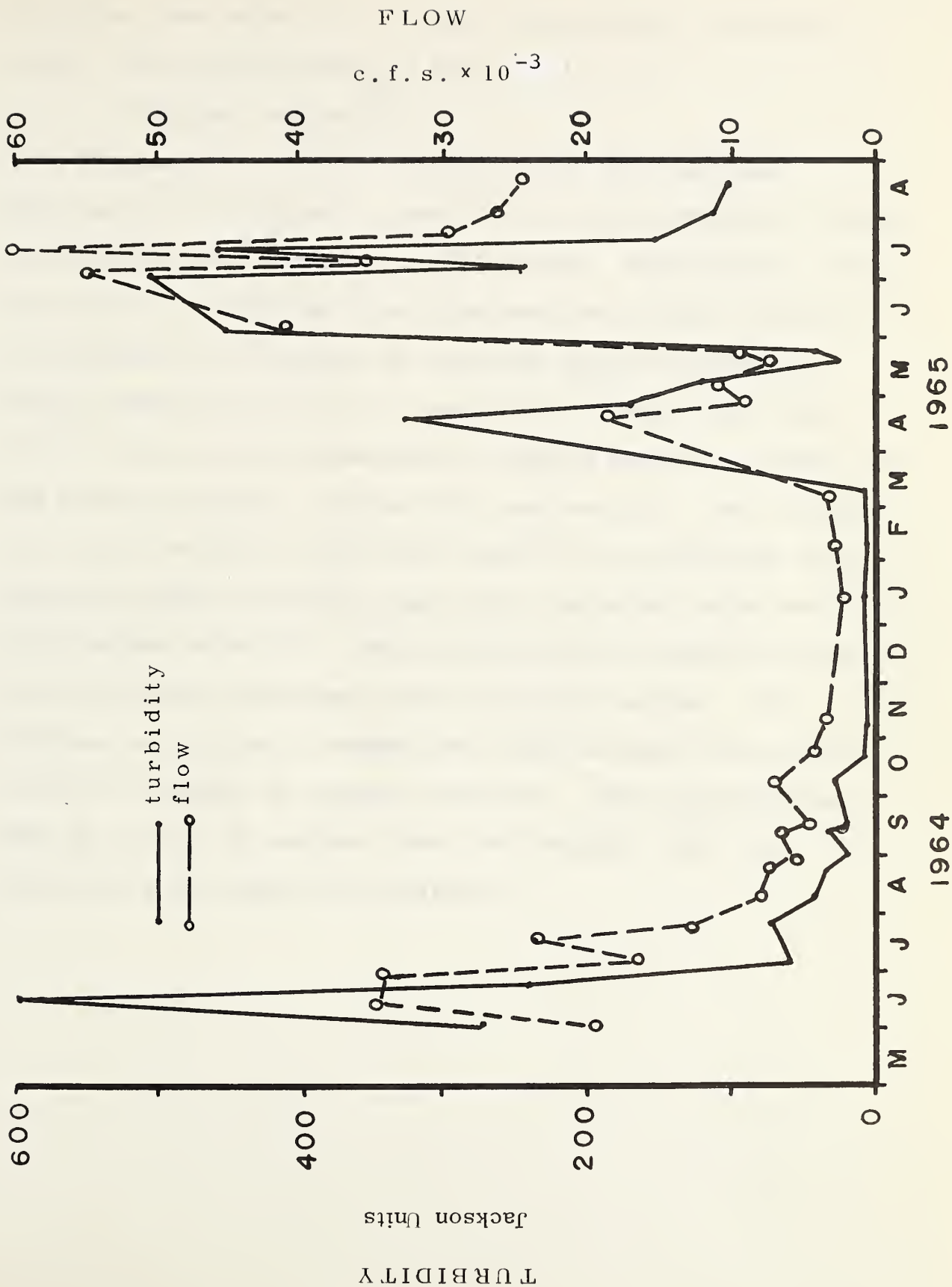


Figure 16. Seasonal variation in turbidity.



in p.p.m., are equal to 1.5 times the turbidity in Jackson units. This relationship is shown in Fig. 17.

b. Regional variation:

The natural variation at peak flows and the great dilution of all effluents, results in little detectable change in turbidity from one station to another. From July 24, 1964 until April 1, 1965 the river flow was low enough to detect a difference in turbidity as the river passed downstream through Edmonton (Fig. 18). During the winter months the river could not be systematically sampled near both shores, so the average increase is shown for each station. The increase of 6 units at Station III was a result of the effluent from the main sewage treatment plant which contained large amounts of suspended materials. These settled quite rapidly and the other effluents contained little suspended matter. The increase at Station II seemed too large and may have been an artifact produced by natural variation. The determinations made at Station VI suggest that the turbidity there was essentially the same as at Station I.

Figure 17. Relationship between turbidity and
suspended solids.

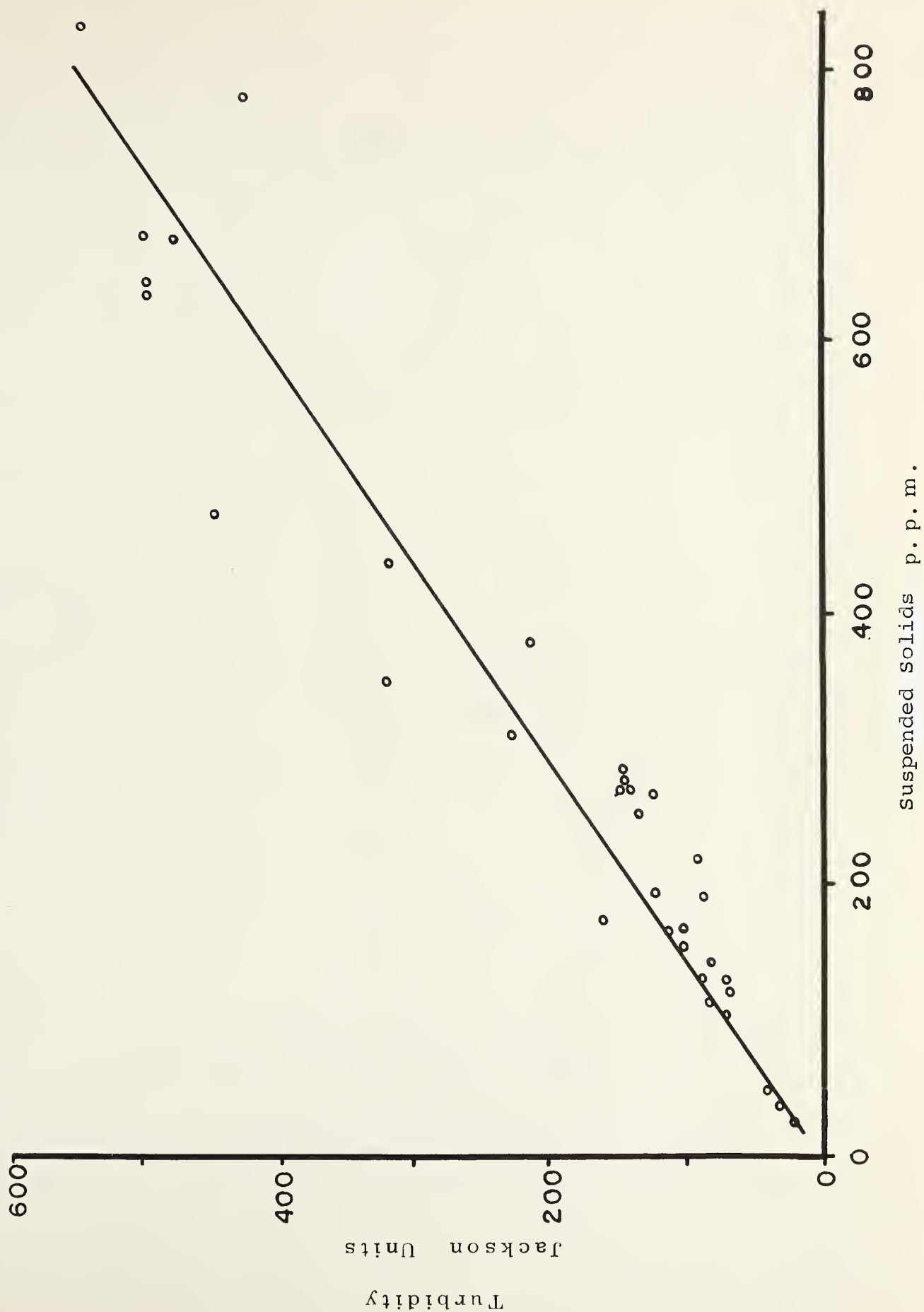
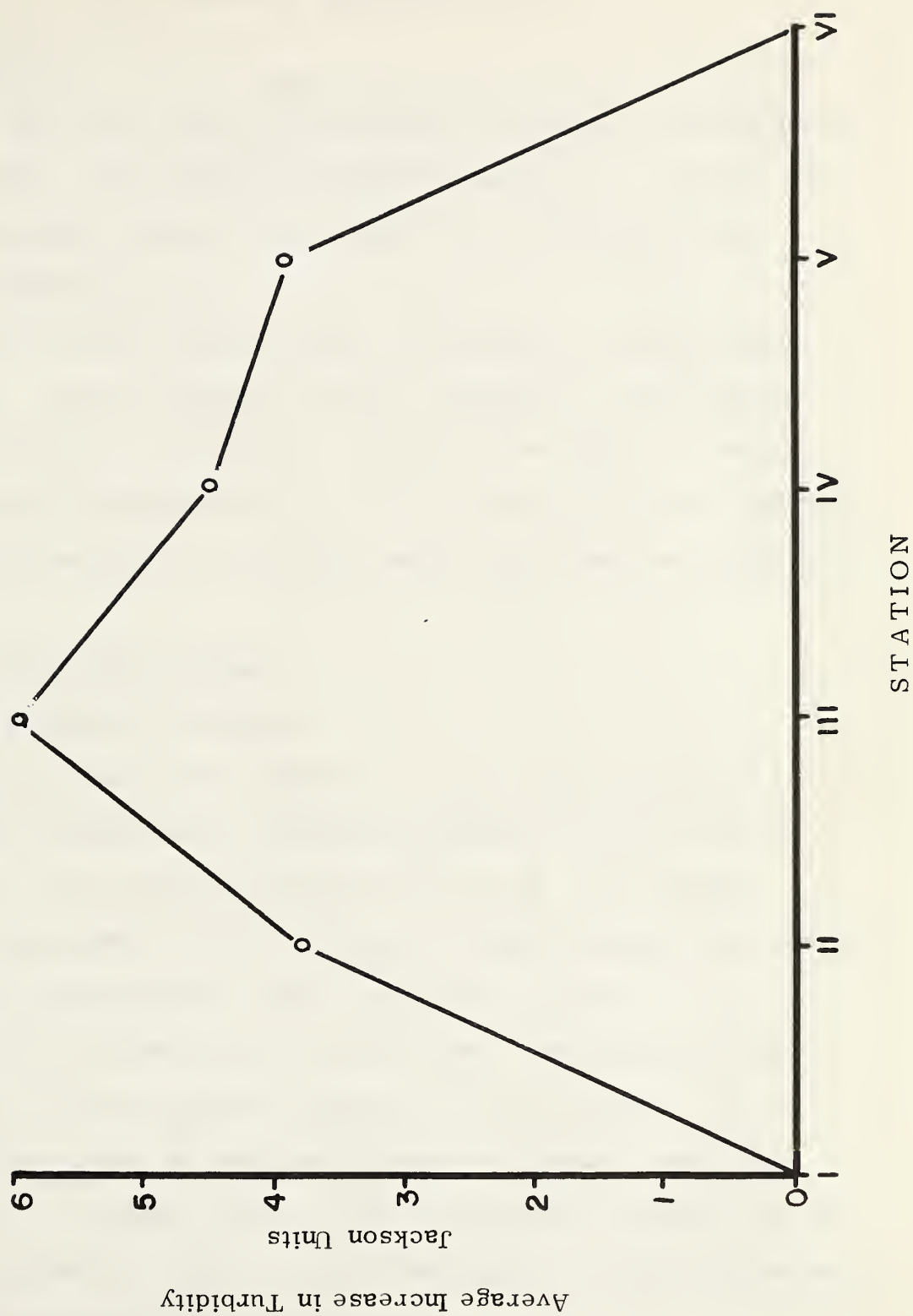


Figure 18. Regional variation in turbidity.
July, 1964 - April, 1965.



VI. CHEMICAL CHARACTERISTICS

1. pH

The pH of the river water within the study area remained quite stable. The absolute range was from 7.7 - 8.5 but few determinations varied by more than ± 0.1 units from the average reading of 8.3.

There is some evidence that the pH was slightly lower in winter. There appeared to be no change in river pH due to the addition of effluents. As the river water is well-buffered with bicarbonate ion it is unlikely that the addition of moderate amounts of acids or bases would have an effect on the pH.

2. Dissolved Oxygen:

a. Seasonal variation:

In the clean water section of the river at Station I the oxygen concentration remained between 75% and 117% of saturation, the yearly average being 92.7%. The oxygen content increased during the winter months although the percent saturation was reduced. This reduction was due to the satisfaction of the B.O.D. of the water. The oxygen thus used could not be replaced, owing to the ice cover. At no time was the river at Station I found to contain less than 7.8 p.p.m. of oxygen. This is well above the critical level reported by Huet (1962) as being necessary for the maintenance of a well-balanced fish population.

On several occasions oxygen determinations were made on samples drawn from different depths. There was no variation, the oxygen content being the same throughout the measurable

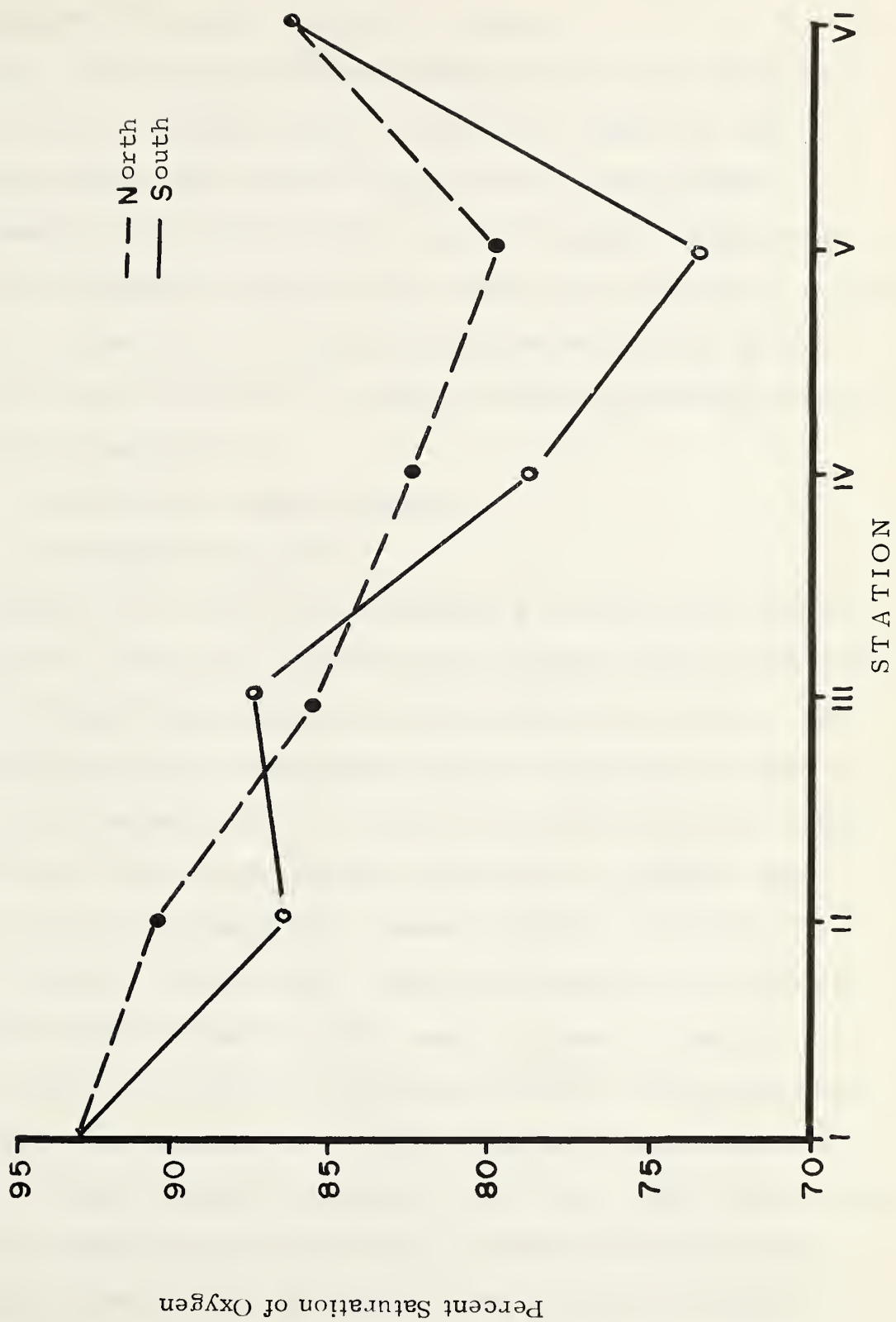
water column.

b. Regional variation:

During the fall and winter the decreased flow and the resulting decrease in effluent dilution resulted in higher B.O.D. values. This caused a decrease in the dissolved oxygen at Station V of as much as 5 p.p.m. but which was more often in the range of 2-3 p.p.m. However, the lowest recorded D.O. was greater than 7.0 p.p.m. In October and early November, when the river was not ice covered, the additional B.O.D. added at Edmonton was largely satisfied by the time the river water reached Station VI and the oxygen concentration returned to near that of Station I. During the period of ice cover this reoxygenation could not occur and a subsequent further decrease was experienced. The Department of Public Health survey for the winter of 1964-1965 found that the average D.O. at Station I was 10.95 p.p.m., while at Station VI it was only 8.80 p.p.m. Downstream there was a continued decrease in oxygen as the B.O.D. was satisfied, until at the Saskatchewan border the average D.O. was only 4.75 p.p.m.

During the summer months there was little or no decrease in D.O. downstream from Station I. Fig. 19 shows the average concentrations of dissolved oxygen found at each station throughout the study period. This is an average of both the summer values, when there was little change, and the winter values, which sometimes showed a marked downstream decrease. The increase in saturation shown at Station III-S was probably because of the addition of the heated effluent from the main sewage treatment plant, the warming effect of which caused an

Figure 19. Regional variation in dissolved oxygen.



increase in the saturation value even though the concentration, as expressed in p.p.m., might not change.

On a few occasions oxygen determinations were made at Station V-S at various times of the day. These did not show any appreciable diurnal variation in concentration. This results from there being no great diurnal variation in effluent discharge into the river which might result in sudden changes in the B.O.D. The algal population density in the river was not sufficient to cause an oxygen reduction at night because of respiration.

3. Biochemical Oxygen Demand:

a. Seasonal variation:

At Station I the river possessed a B.O.D. which ranged from 0.28 - 3.20 p.p.m. There was no direct correlation with flow, although the average value was higher in winter. In the ice-cover period the reduced water temperature slowed the rate of decomposition. Thus, any organic material added to the river from towns further upstream, or perhaps leaf litter from the Brazeau Dam, reached Station I with its B.O.D. largely unsatisfied. During the summer the B.O.D. at Station I was dependent on the load of organic material. A sudden rise in the flow of tributaries of the river can have the effect of flushing large quantities of organic detritus into the water and this increases the B.O.D. When the increased flow has prevailed for some time, it serves to dilute the existing concentration of organics and the B.O.D. drops. Because of this, both the highest and lowest B.O.D. values at Station I were recorded during the summer months when the

flow was in excess of 40,000 c.f.s.

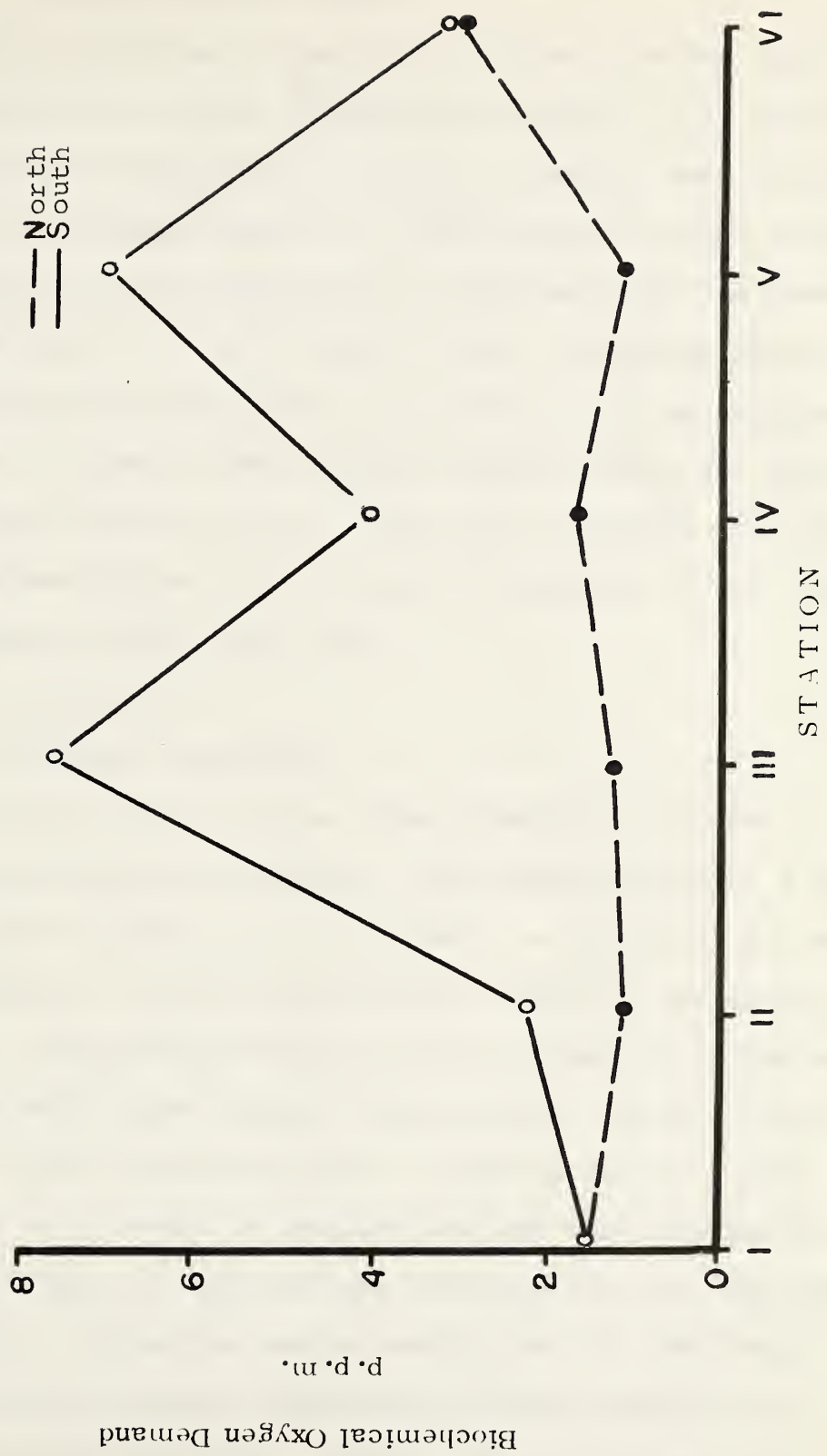
b. Regional variation:

Fig. 20 shows the yearly average B.O.D. at each station. Due to the reduction of effluent dilution, the B.O.D. at Stations II - V near the south shore was higher during the winter. During this period the B.O.D. at Station V-S was found to be as high as 17.0 p.p.m. From the graph it can be seen that additions of high B.O.D. effluents occurred at both the main sewage treatment plant and at Chemcell Ltd. The reduction at Station IV-S was due to oxidation, mixing, and the settling of sewage solids.

It will be seen that with the exception of Stations IV-N and V-N, the stations nearer the north bank showed a B.O.D. which was slightly lower than that found at Station I. This is difficult to explain but could be partly due to the heating effect of the city power plant, which would increase the rate of oxidation. The effluent from the water treatment plant may also contribute to this decrease. The chemicals present in this effluent are those which are used for the clarification of the river water and retain their activity after discharge into the river.

On April 15, 1965 the B.O.D. at Station II-S was found to be 7.88 p.p.m. which was in excess of the normal range found at that site. The sudden increase in flow at that time served to take into suspension the sewage solids which had settled out below the 105 St. sewage treatment plant during the low winter flows.

Figure 20. Regional variation in biochemical oxygen demand.



4. Complete Oxygen Demand:

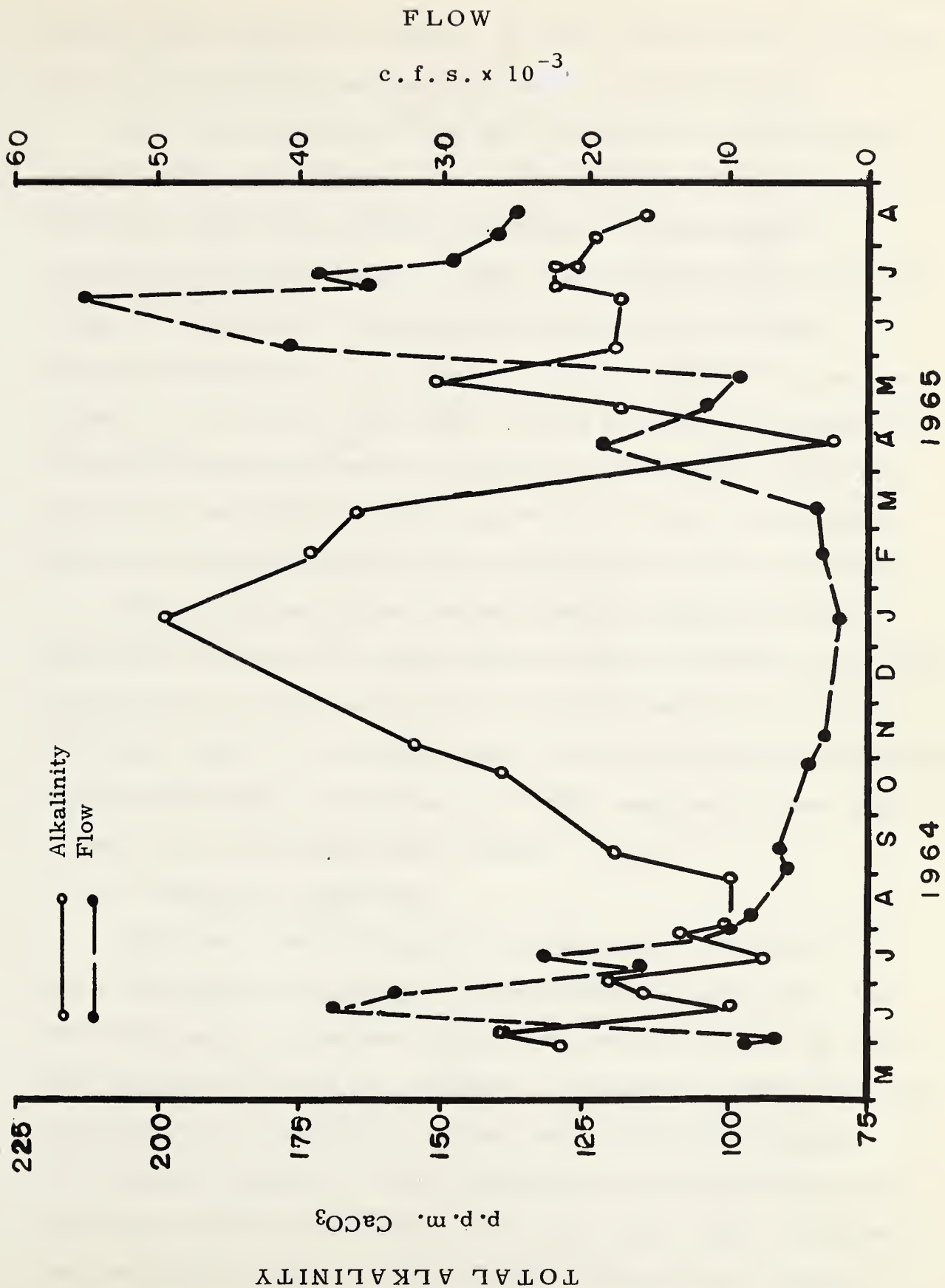
On five different occasions a series of water samples were taken from various stations and treated as if for B.O.D. determinations except that individual samples were incubated at 20°C for extended periods. The remaining oxygen concentration was usually determined in samples which had been incubated for 5, 7, 12, 17 and 22 days. Although there was a great deal of variability in the results it was apparent that from 77-100% of the complete oxygen demand was satisfied within the first five days. This would indicate that the B.O.D. determinations are an accurate measure of the oxygen requirements of the river water.

5. Alkalinity:

a. Seasonal variation:

As shown in Fig. 21 the total alkalinity showed an inverse correlation with flow. The range at Station I was from a high of 199 p.p.m. in winter to a low of 81 p.p.m. at spring breakup. This wide range was owing to variation in run-off. During the winter the flow was mainly ground water which had percolated through rock and soil and had acquired a load of dissolved materials. In the spring, the water entering the river as a result of melting ice and snow greatly diluted the river water to decrease the concentration of many chemical components. During the summer months the rain and melt waters passed over and through permeable unfrozen ground to be discharged into the river carrying some dissolved salts. This maintained the total alkalinity at a higher value during the summer than in the spring. The high levels during the

Figure 21. Seasonal variation in alkalinity.



winter were also due, in part, to the 'freezing-out' from the ice. An ice sample had an alkalinity of only 8 p.p.m.

The total alkalinity can be a measure of bicarbonates, carbonates or hydroxides. In the North Saskatchewan River only the first two of these are present in measurable quantities (Theroux et al., 1943). Phenolphthalein alkalinity, which is a measure of carbonate concentration, remained remarkably constant at 3.5 p.p.m. CaCO_3 , although an extreme range of 0-15 p.p.m. was found. These extreme values were not associated with effluents or changes in flow. The carbonate alkalinity amounted to less than 4% of the total alkalinity with the bicarbonate ion being responsible for the remainder.

Table V compares the average chemical composition of the water of the North Saskatchewan River at Station I with the average of all open basin waters of North America as listed by Clark (1924). This shows that the concentrations of carbonates and bicarbonates, as well as most other components, are very close to the North American average.

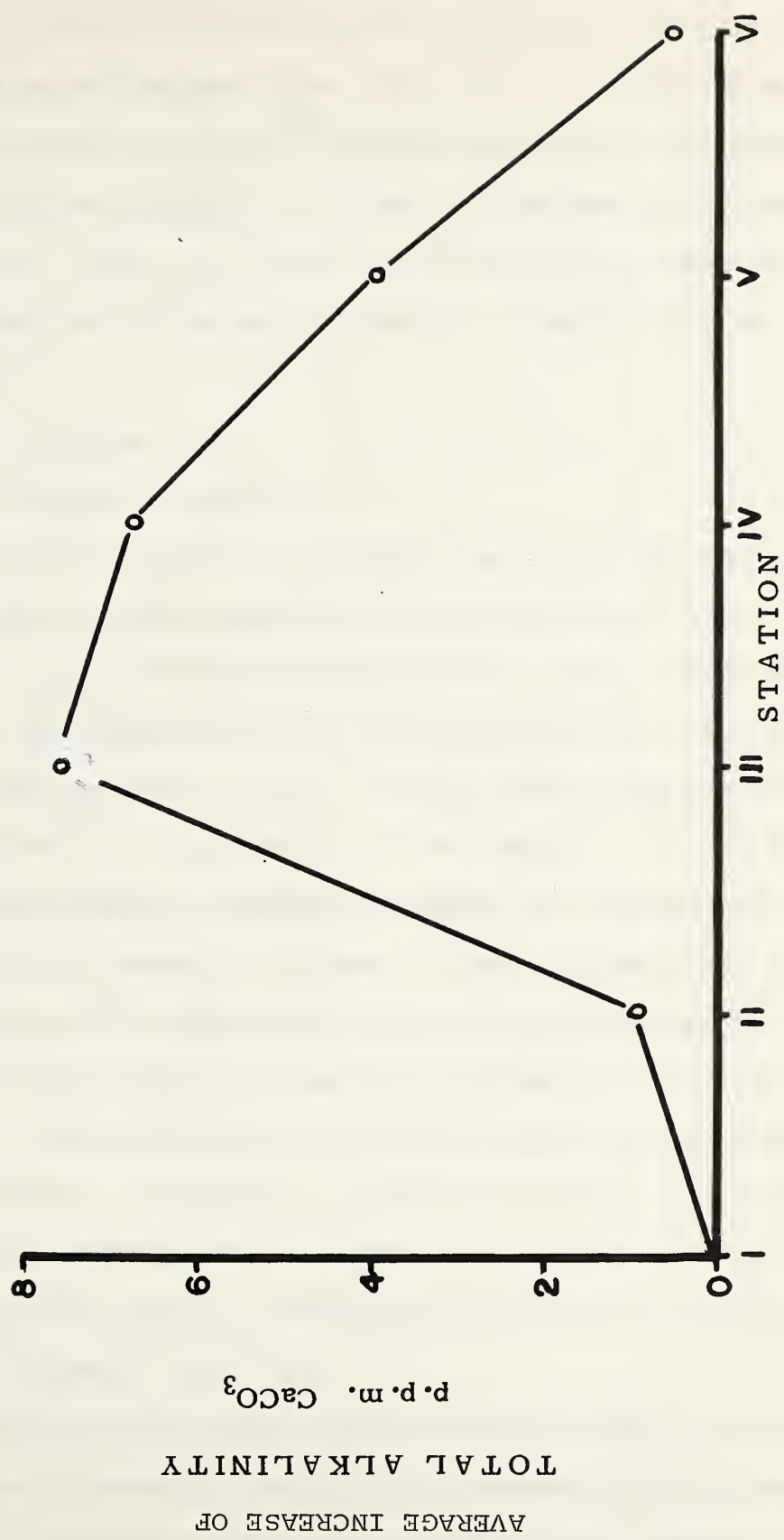
b. Regional variation:

There was some modification in the total alkalinity of the river due to the addition of effluents at Edmonton. The most noticeable increases occurred during periods of low flow when effluent dilution was reduced. Because of normal seasonal variations it is difficult to deal with absolute increases, so the average increase at each station was determined by using the values found at Station I as a zero base. Fig. 22 shows the average increase at the different stations as found by averaging all determinations completed during the study period.

Table V. Comparison of the Chemical Composition of the North Saskatchewan River with the North American Average for Open Basins (Clark, 1924).

Component	North American Average %	North Saskatchewan River %
$\text{CO}_3, \text{HCO}_3$	33.4	40.0
SO_4	15.3	18.8
Cl	7.4	2.7
NO_3	1.2	0.3
Ca	19.4	19.9
Mg	4.9	5.9
Na	7.5	8.1
K	1.8	1.6
$(\text{Fe}, \text{Al})_2\text{O}_3$	0.6	0.03
Si	8.6	2.7

Figure 22. Regional variation in alkalinity.



Not enough determinations were done near both shores to show the differences between them. The return to near normal concentrations at Station VI after the extensive increase at Station III was thought to be due to the precipitation of carbonates. This is in part borne out by the substrate analyses which showed an increase in substrate conductivity at Station V (p.80).

6. Chloride:

a. Seasonal variation:

During the period from early June until the end of October the chloride concentration at Station I had a range of 6.2 - 9.1 p.p.m. with an average of 7.1 p.p.m. From November until the beginning of June, the range was 2.3 - 4.5 p.p.m. with an average of 3.3 p.p.m. Within these two periods the variation was not a product of flow changes. In the winter months many chemical components showed an increase in concentration for reasons outlined in the discussion of alkalinity. Why the chlorides showed the opposite distribution is unknown, although an analysis of river ice yielded a concentration of 2.5 p.p.m., which was only slightly lower than the water concentration at that time. Thus the ice does not concentrate the ion by 'freezing-out', but this does not entirely explain why there was a drop in concentration during the winter.

b. Regional variation:

During the high flow rates of summer there was little detectable increase in the chloride concentration from effluent addition. At Station III-S the content was slightly higher (1 p.p.m.) than further upstream but as mixing progressed this

increase could not be detected at Station IV. During the winter the reduced flow allowed a much greater increase. At Station V-S this approximated 7.0 p.p.m. or an average increase of more than 200% over the winter clean-water zone average. At Station VI the increase was still noticeable but not to the same extent.

7. Fluoride:

Fluoride determinations were carried out on limited occasions. The absolute range found was 0.04 - 0.40 p.p.m., but this wide variability was not the result of any seasonal fluctuations. A few analyses were completed on samples collected from the various stations on the same day. These did not suggest any change in fluoride concentration because of effluent addition.

8. Nitrogen:

A. Ammonia Nitrogen:

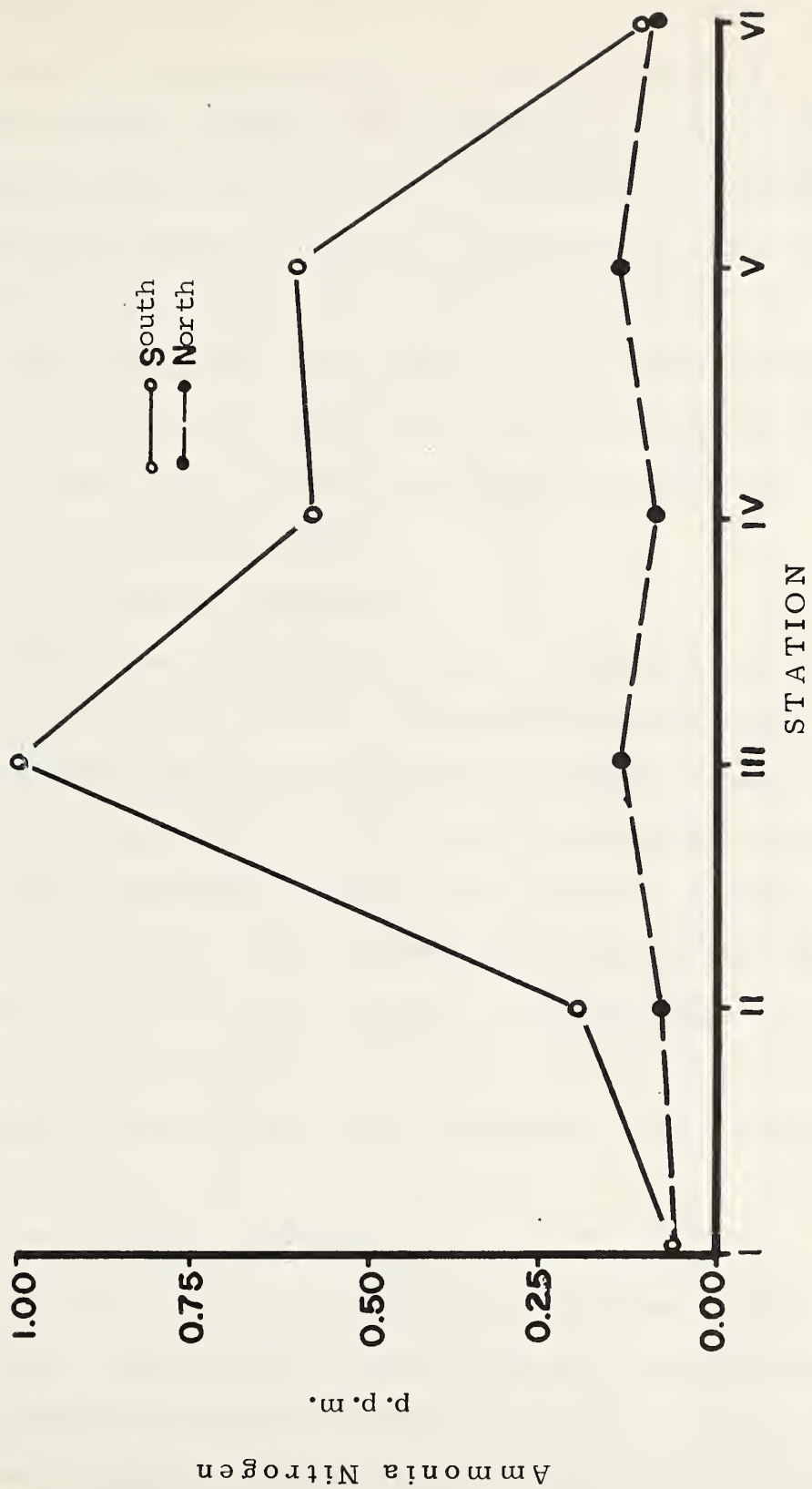
a. Seasonal variation:

Determinations of this compound were not attempted until January of 1965 so there are not enough data available to show the complete seasonal cycle. The range at Station I was found to be 0 - 1.20 p.p.m. Within this range the higher values were found before breakup, thus suggesting that the natural concentration of ammonia does display a seasonal cycle.

b. Regional variation:

Fig. 23 shows the average concentration of ammonia nitrogen found at all stations. At Station III-S the concentration varied from 7 - 23-fold greater than at Station I

Figure 23. Regional variation in ammonia nitrogen.



due to the effluent from the main sewage treatment plant. Mixing and oxidation caused an initial decrease at Station IV-S, but the effluent from Chemcell Ltd. again increased the concentration at Station V-S. By Station VI oxidation had reduced the ammonia nitrogen concentration until it was only slightly higher than that found at Station I.

Near the north shore there was a slight increase in this compound at Stations II - V, but as was the case near the south shore, the increase was less at Station IV.

B. Nitrite Nitrogen:

a. Seasonal variation:

The range found at Station I throughout the study period was 0.001 - 0.010 p.p.m. Although these are very small values the method of analysis had a range of only 0 - 0.20 p.p.m. As shown in Fig. 24, the concentration was lowest in the fall and winter when the flow was at a minimum. During periods of high flows the concentration was greater. The peak in April of 1965 was a product of ice breakup. It will be noted that nitrite nitrogen shows a positive correlation with flow while many of the other compounds show a negative correlation.

b. Regional variation:

As shown in Fig. 25 there was a marked change in nitrite nitrogen concentration in the river due to effluent addition. The increase at Station III-S was a result of the effluent from the main sewage treatment plant. The rapid drop in concentration at Station V and the return to near normal concentration at Station VI was a product of oxidation.

Figure 24. Seasonal variation in nitrite nitrogen.

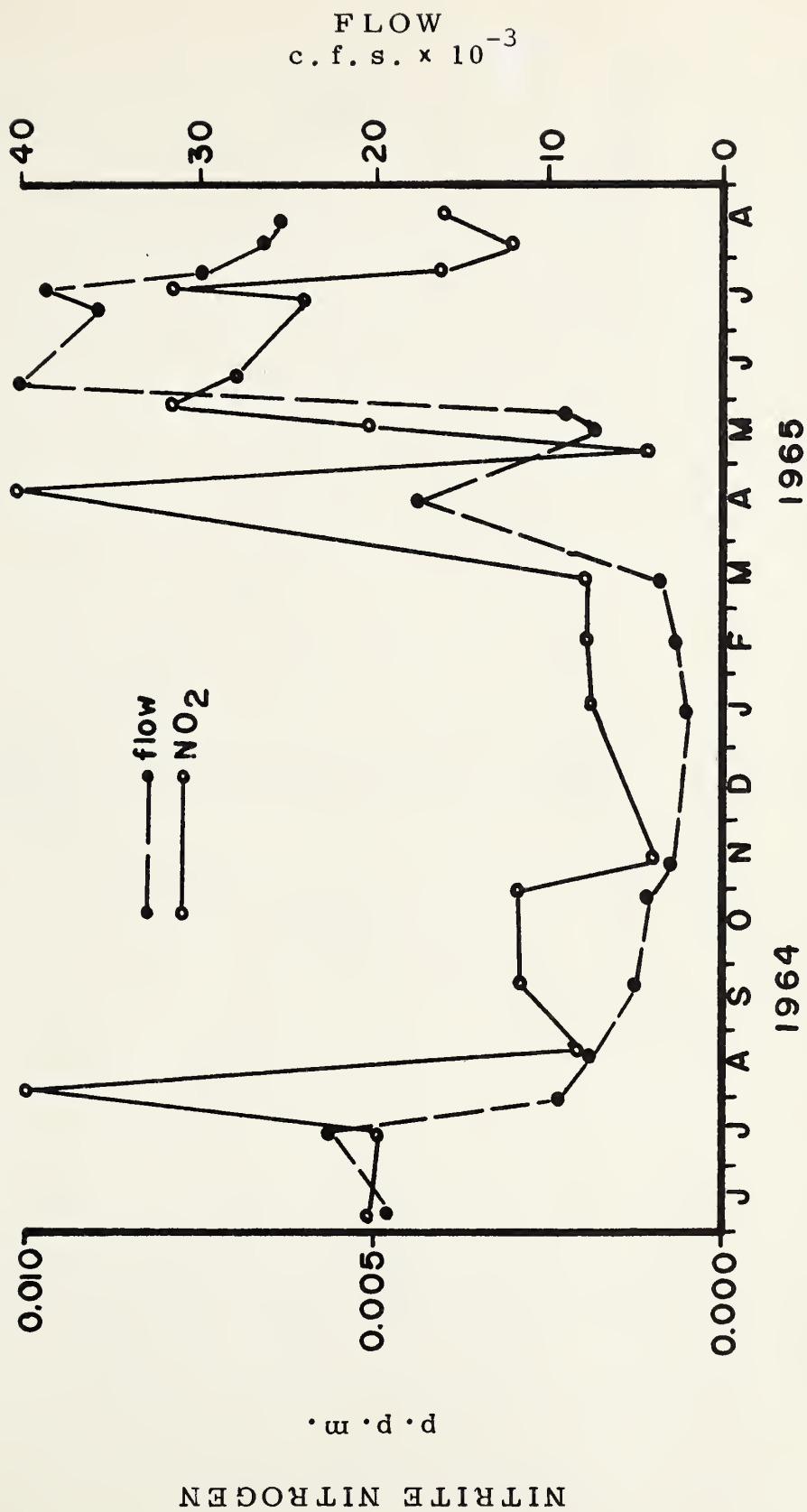
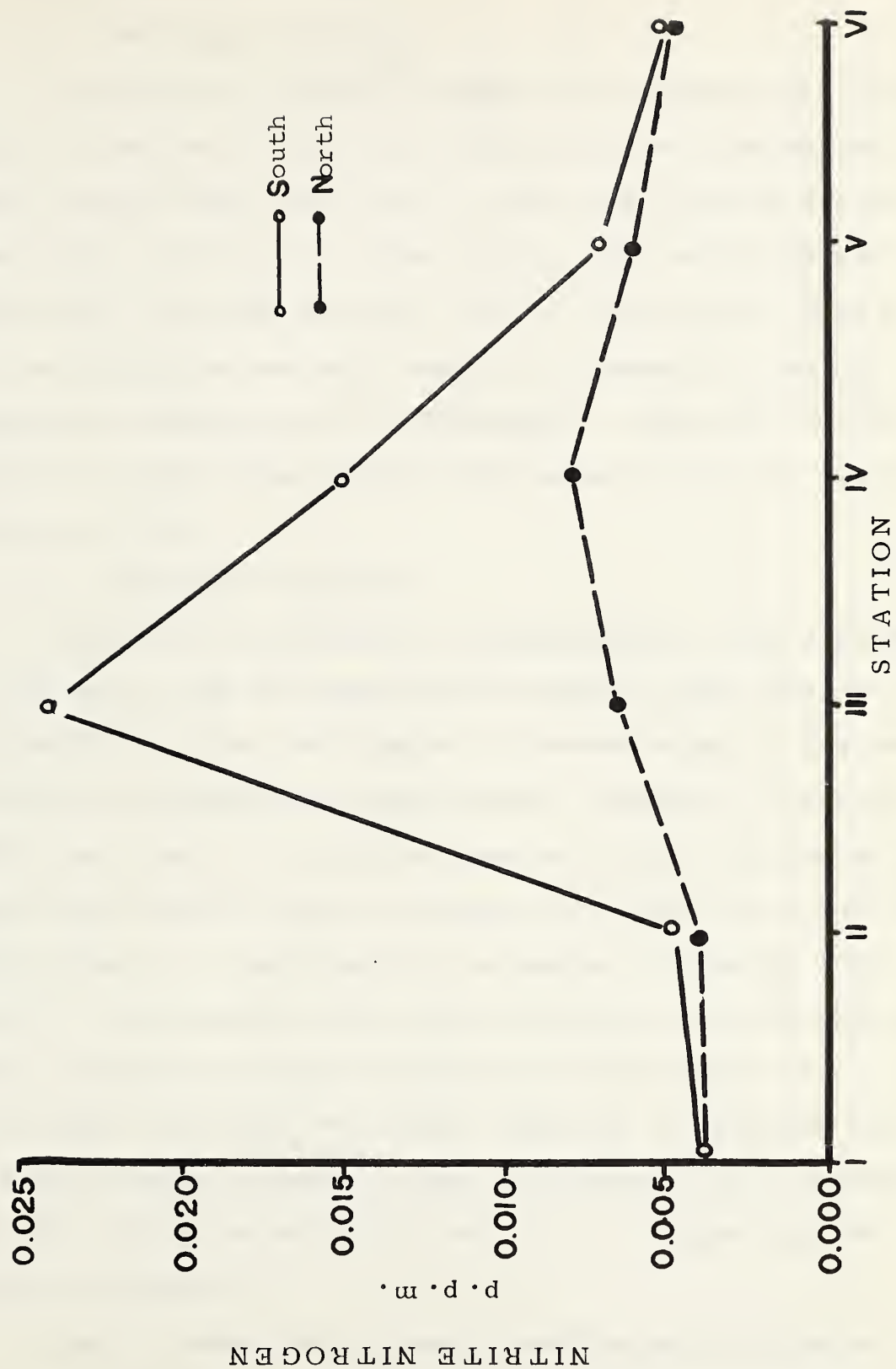


Figure 25. Regional variation in nitrite nitrogen.



C. Nitrate Nitrogen:

a. Seasonal variation:

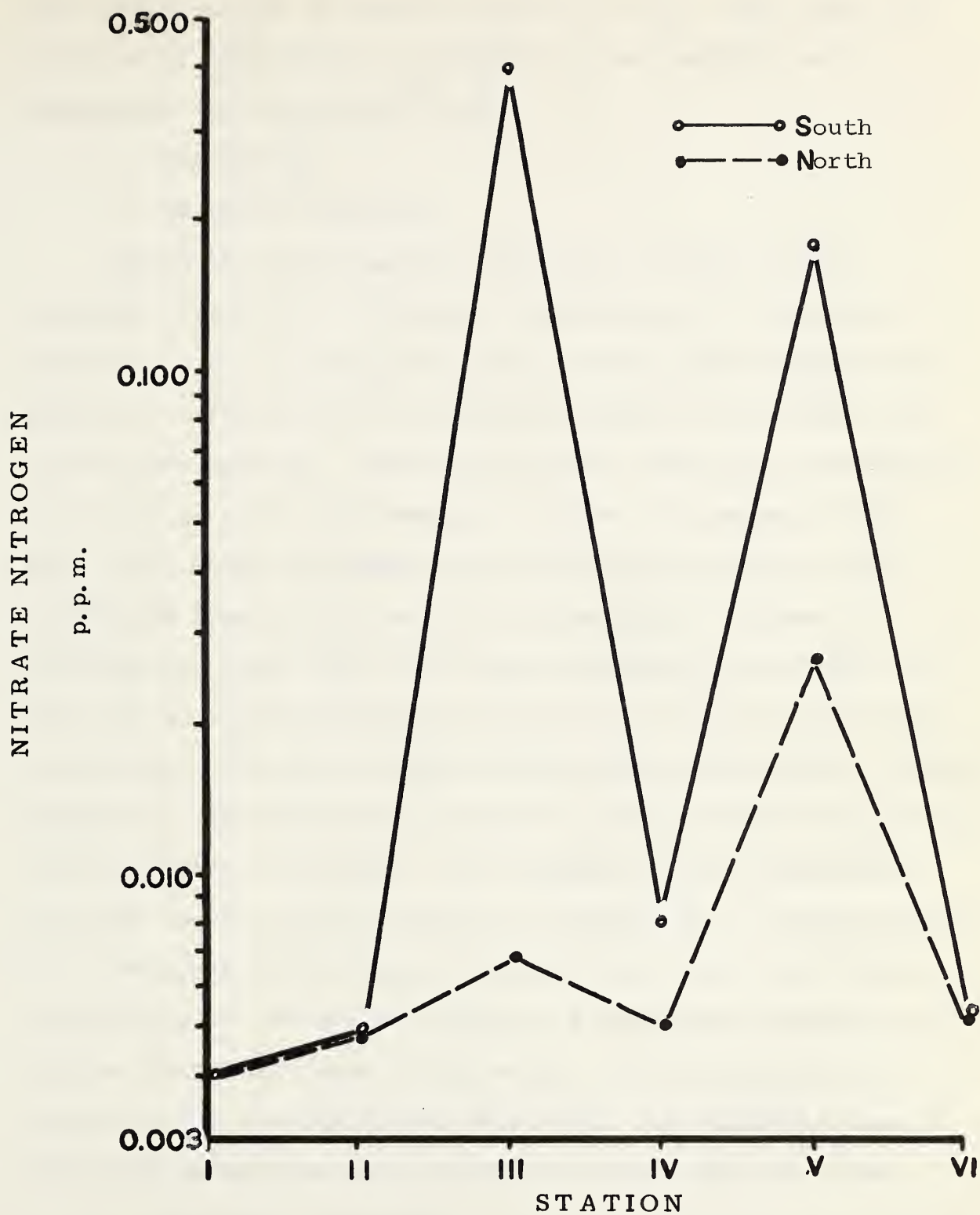
Analysis for nitrate nitrogen was not begun until October 24, 1964 and as a result the data are not very extensive. From the starting date until July 12, 1965 the range at Station I was 0.35 - 0.90 p.p.m. From July 15, 1965 until the end of the study the range was only 0.003 - 0.008 p.p.m. This drop in concentration was not a result of changes in flow and no reasonable explanation is forthcoming. Within the initial period of high concentrations the variation was not due to season or flow.

b. Regional variation:

Because of the paucity of determinations, the dependence on dilution, and the unexplained change in late July, it is impossible to plot the changes in concentration at the various stations throughout the study period. However, it was found that there was a 1.5-fold increase at Station V-S during the high water periods and an increase of as much as 53-fold during the winter. On one occasion the reading at Station III-S was 200 times greater than that at Station I on the same day. Such increases are not noticeable at Station IV-S so it is concluded that there were major additions of nitrates from the main sewage treatment plant and Chemcell Ltd. At Station VI the nitrate concentration was 1.2 - 1.5 times greater than at Station I.

Fig. 26 shows the average concentration of nitrates between July 19 and August 12, 1965. This was after the unexplained drop in natural concentration and during a period

Figure 26. Regional variation in nitrate nitrogen,
July - August, 1965.



when the flow was in excess of 20,000 c.f.s. This shows an increase of 53-fold at Station III-S and another which approaches this at Station V-S.

9. Phosphates:

a. Seasonal variation:

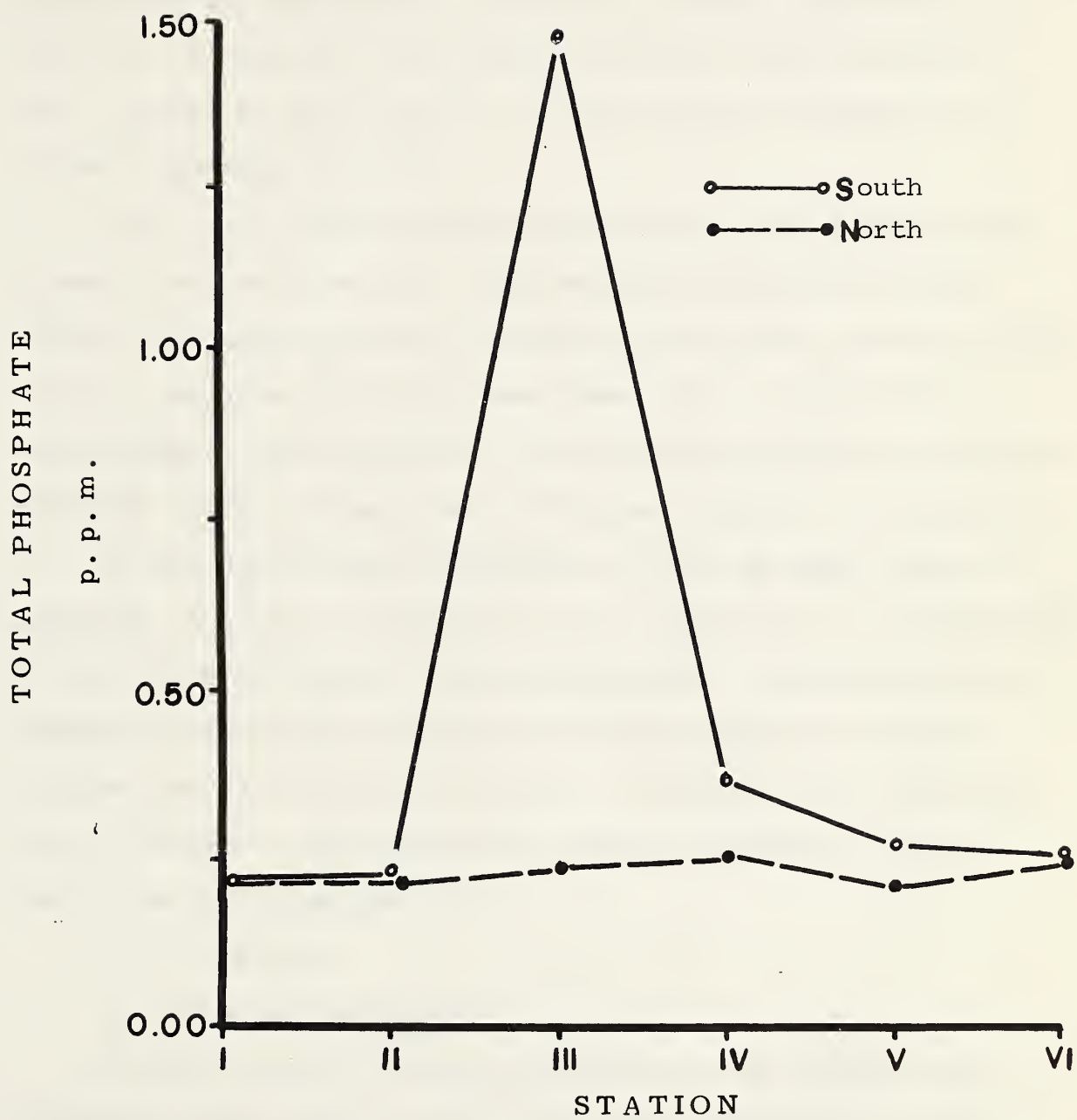
During the study period the range in total soluble phosphate was 0.07 - 0.79 p.p.m. at Station I. The normal range was 0.07 - 0.28 p.p.m. with the only value beyond this being the value of 0.79 occurring on April 15, 1965 when the ice was breaking up. Hutchinson (1957) states that phosphates are found in only trace amounts in snow. Consequently the melt water which increases the flow at breakup should not contribute appreciable amounts of phosphate. A piece of floating ice taken from the river at Station VI on April 23, 1965 had an ortho-phosphate content of 0.25 p.p.m. which was in excess of the river water content during the winter. Perhaps phosphates are effectively trapped in the ice and then released into the water at breakup. No reference to this phenomenon has been found in the literature, although it is substantiated by an analysis of ice taken from Big Island Lake near Edmonton in February of 1965 which displayed a phosphate concentration greater than that found in the water. This concentrating effect of the ice may be the reason for the concentrations of dissolved phosphates being higher in summer than in winter.

b. Regional variation:

Fig. 27 shows the average concentration of total soluble phosphates at the various stations during the summer of 1965. It is obvious that there was a great addition of phosphates

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Figure 27. Regional variation in phosphates,
Summer, 1965.



at the main sewage treatment plant. The rapid disappearance of the added phosphate would suggest that it was utilized biologically or was absorbed in the mud. Substrate analysis suggests that absorption is the most feasible explanation (p.88). Biological utilization could not have been great for, as will be shown (p.79), algae were not abundant downstream from Station III-S.

Fig. 27 is based on the concentrations found during the summer when the river flow, and consequently the diluting effect, was approximately ten times greater than average winter values. Because of this it was found that in the winter the phosphate concentration at Station V-S could be as much as thirteen times greater than at Station I (0.22 - 2.95 p.p.m.).

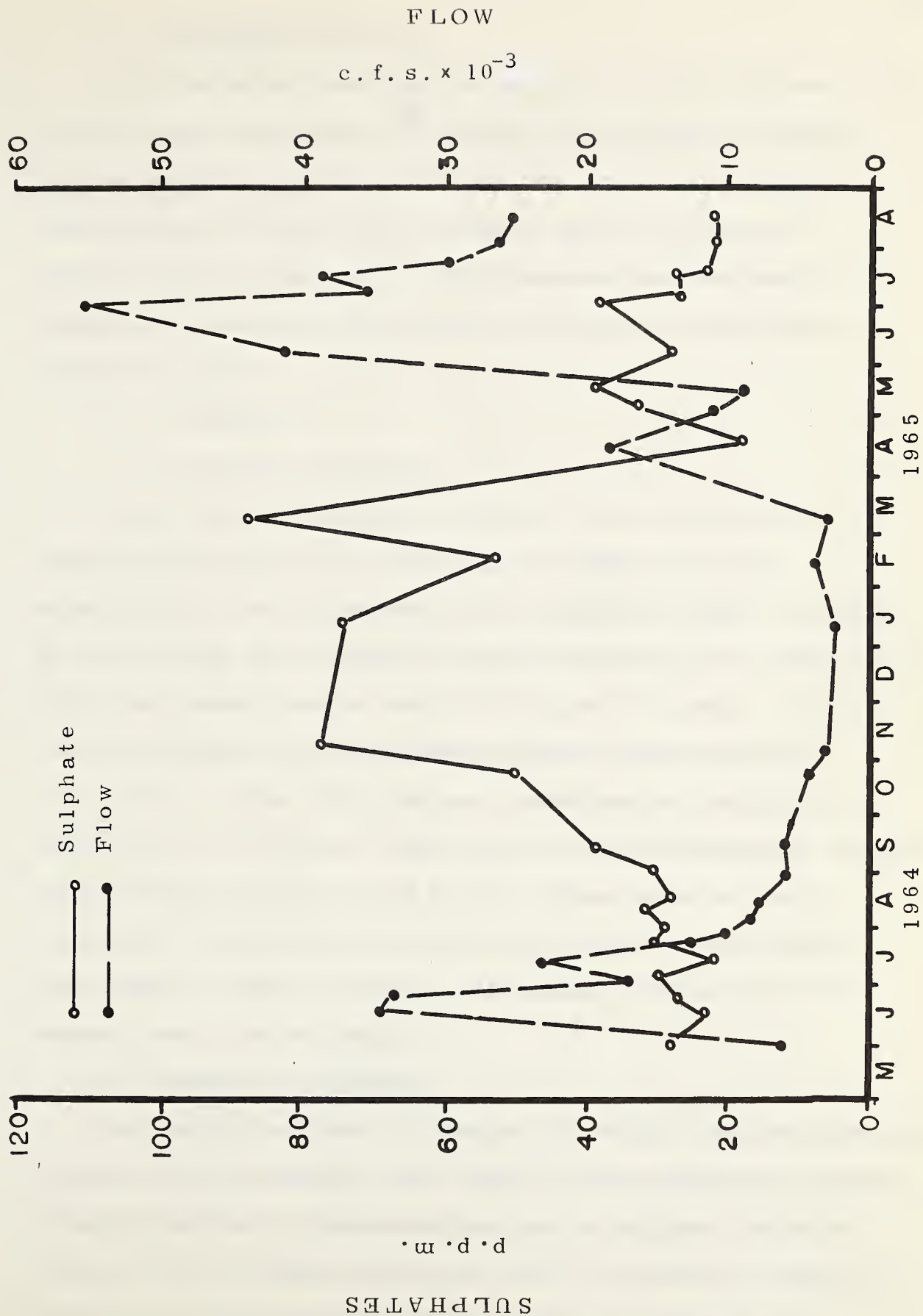
In the discussion of plankton it will be seen that the increase in algae at Station VI was in part due to the increase in available nutrients, mainly phosphates. Although in the summer the increase in concentration of phosphate at this station averages only 0.03 p.p.m., it results in a continuous flow of soluble, and presumably usable, phosphate, approximating one kilogram per hour.

10. Sulphate:

a. Seasonal variation:

As shown in Fig. 28 the concentration of sulphate was modified by the rate of flow. The range found was 18 - 88 p.p.m. The higher values were found during the winter and the lowest value was recorded at breakup. The high values found during the summer of 1965 were a result of the heavy rainfall which brought in sulphates from tributaries.

Figure 28. Seasonal variation in sulphates.



b. Regional variation:

When the river was high the dilution of all effluents was so great that there was little noticeable change in concentration between stations. During the autumn and winter the concentration at Station V-S ranged from 4 - 43 p.p.m. greater than at Station I. This increase was the result of sulphates introduced in the effluent from the main sewage treatment plant.

11. Chromate:

a. Seasonal variation:

From June 1, 1964 until March 8, 1965 the range of concentration was 0.01 - 0.07 p.p.m. There was some evidence that the concentration was slightly higher in winter as the average from October to March inclusive was 0.055 p.p.m. while the summer average was 0.028 p.p.m. On April 15, 1965 the concentration had increased markedly and remained so until July 2, 1964. The average concentration during this period was 0.144 p.p.m. After July 2 the concentration dropped to an average value of 0.08 p.p.m. There seems to be no explanation for the great variations which occurred during the summer of 1965 or why the differences between the two summers should be so great.

b. Regional variation:

Not enough analyses of samples collected from the different stations on the same day were done to give conclusive evidence of modifications in concentration due to effluent addition. However, this is some indication that an increase of approximately 0.01 p.p.m. occurred from Station I to Station V.

12. Hardness:

a. Seasonal variation:

The total hardness of the river water at Station I was correlated with flow as shown in Fig. 29. The range found was 80 - 225 p.p.m. as CaCO_3 . The higher values were found during the winter months while the minimum value was a product of the dilution by the melt water at breakup. It is thought that the correlation between flow and hardness was less in the summer of 1965 because the fluctuations in water volume were largely due to extensive rainfall in the drainage basin. Ice and snow melt at the headwaters was the prime cause of the flow fluctuations in the summer of 1964. Rainfall percolates through soil and reaches the river with a total hardness much in excess of that found in melt water. Thus, rapid increases in flow due to rainfall do not cause sharp decreases in the total hardness of the water.

Following the classification of Thomas (1953) the river water during the period April to September is hard and during the rest of the year very hard.

Hardness due to both calcium and magnesium salts was determined. As the two fluctuate together the results have been dealt with as total hardness. The hardness due to magnesium salts accounted for 28-34% of the total hardness.

b. Regional variation:

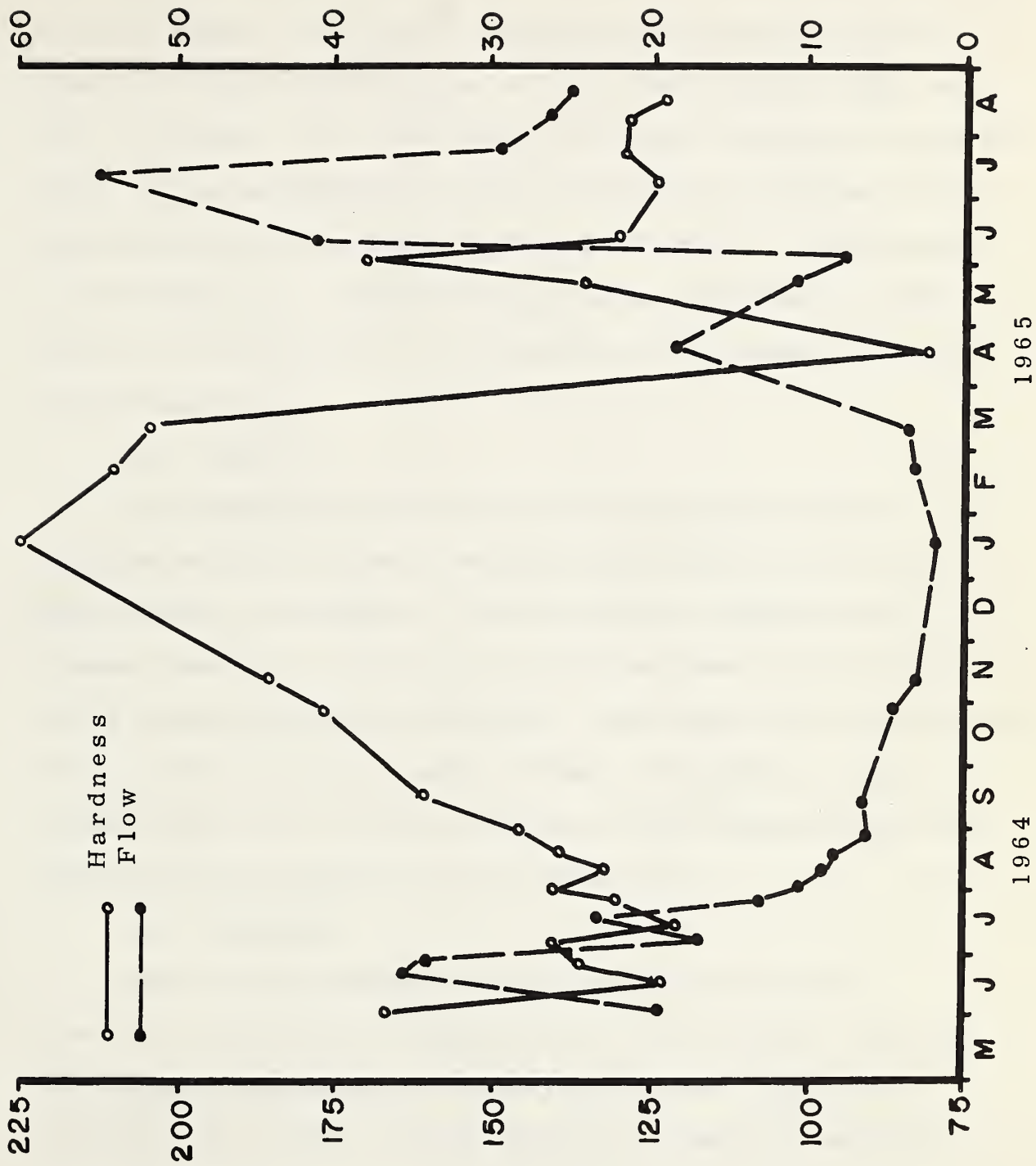
During this study it was found that the salts of calcium and magnesium were not homogeneously distributed in the river. When samples were taken within a two-day period at one station, the observed changes in hardness were much greater than would

Figure 29. Seasonal variation in hardness.

TOTAL HARDNESS

p.p.m. CaCO_3

Hardness
Flow



be predicted on the basis of changes in flow. This was also true when samples were extracted from one site within minutes of each other. Also, with respect to the concentration at Station I, the concentration at any other station might vary by ± 25 p.p.m. It is not known why these variations occurred. Thus, it is impossible to show accurately any changes which might have occurred due to effluent addition. It did appear as if there was a slight average increase at Station III-S and V-S, but by Station VI there was no noticeable increase over Station I.

13. Calcium:

The concentrations of calcium and magnesium were calculated from hardness determinations and thus show the same trends as hardness. The calcium ion concentration ranged from 20.4 - 66.4 p.p.m. with the lower values being found during periods of high flow. The low value of 20.4 p.p.m. was a product of the diluting effect at breakup. There is some evidence of a slight increase in the concentration of this ion between Station I and Station V.

14. Magnesium:

This ion displayed a seasonal cycle parallel to that of calcium with a range of 7.1 - 16.5 p.p.m. Although the absolute increase, or even the direction, was not constant, there was a slight average increase in concentration from Station I to Station V.

15. Copper:

The average concentration of copper in the river was 0.31 p.p.m. The majority of analyses yielded a figure close

to the average but there were a few samples which gave a wide range of values (0.05 - 0.79 p.p.m.). There is no evidence of a yearly cycle in concentration or of a change as the river passed downstream through Edmonton.

16. Iron:

a. Seasonal variation:

The method used for analysis measured soluble ferrous and ferric ions and iron suspensions which might occur in natural waters.

In the present study there was found to be an iron concentration in the river which varied from 0.02 - 0.63 p.p.m. From mid-June until early spring the concentration of iron ranged from 0.02 - 0.08 p.p.m. The spring melt carried run-off water into the river which must have had a high iron content as the average concentration for the period April 15 to June 5 was 0.27 p.p.m., while for the rest of the year the average was only 0.05 p.p.m. In many of the small intermittent streams, as well as the larger permanent Whitemud Creek, there were extensive deposits of iron oxides on rocks and debris. These oxides were probably swept into the river in the early spring.

In the summer of 1965 the heavier rainfall caused the tributaries to maintain a higher rate of flow than was experienced in 1964. For this reason the iron content of the river remained well above the 1964 summer average until mid-July.

There was no change in concentration with fluctuations in river flow in either the summer or winter.

b. Regional variation:

There is no evidence from the analyses to suggest that iron-containing effluents entered the river within the study area.

17. Manganese:

The cold periodate oxidation method used for the determinations of manganese had a range of detection from 0 - 10 p.p.m. As the concentrations found in the river never exceeded 0.40 p.p.m., the accuracy of the analyses are low. Concentrations of manganese were quite variable within the range 0 - 0.40 p.p.m. There did not seem to be any variation which could positively be correlated with season, flow, or the addition of effluents.

18. Silica:

a. Seasonal variation:

The method used for analysis measured silica as silica oxide. The absolute range found was 3.60 - 8.60 p.p.m. During the autumn and winter months of 1964-1965, the average value (6.18 p.p.m.) was higher than the average for the preceeding summer (4.90 p.p.m.). This would seem to indicate a normal seasonal variation as displayed by many other chemical components. During the summer of 1965 the average was 5.80 p.p.m. until August when the concentration dropped to 4.00 p.p.m. The high values recorded during the summer of 1965 occurred during the highest flow rates experienced during the study period. Perhaps the higher than average values recorded in the early summer of 1965 and the subsequent drop in August were not directly due to the flow in the river, but

rather the relative flows in the tributaries.

b. Regional variation:

Analysis for silica was not done often enough at all stations to show individual variation. The greatest number of determinations were done at Station I and Station V. These show that the increase at Station V ranged from 0 - 1.45 p.p.m. with an average of 0.51 p.p.m.

18. Phenols:

a. Seasonal variation:

Phenolic compounds are important in water supplies as they can impart an unpleasant taste to the water as well as being toxic to fish and other aquatic organisms (Klein, 1959). In the present study, determinations of phenols were not begun until January, 1965. The range found at Station I was 0 - 0.060 p.p.m. with an average of 0.022 p.p.m. As concentrations even this small are not common in natural water, it is likely that these values were the result of oil processing operations upstream at Devon and Drayton Valley. Concern has been expressed by the Provincial Public Health Department that the concentration may increase due to the decomposition of leaf litter on the bottom of the Brazeau impoundment. Not enough analyses were done to show the seasonal variation which might be expected at Station I if the addition of phenols upstream remained relatively constant while the river flow fluctuates.

b. Regional variation:

Again not enough data are available to show the variations at all stations, but it was found that the concentration at

Station V ranged from 0.028 - 0.135 p.p.m. which was an increase of two to five-fold over Station I. Klein (1959) lists the lethal concentration of phenols for fish to be 1 - 10 p.p.m., while Cole (1941) quotes several authors who place the lethal level to be within the range 5 - 20 p.p.m. All these are well above the highest concentration found in the river. However, Klein (1959) quotes the work of Kalabina who found that fish are usually absent from areas where the concentration was 0.2 p.p.m. Huet (1962) has stated that concentrations as low as 0.02 p.p.m. can taint fish flesh and this may explain the reports of contaminated fish which have been received by the Department of Public Health (p. 23). If the work of Huet and Kalabina is correct, then it might be expected that in the North Saskatchewan River the fish may be affected at times of extreme low flow rates and immediately below the points of entry of phenol containing effluents.

20. Synthetic Detergents:

The method of analysis measures the concentration of anionic synthetic detergents in p.p.m. of alkyl benzene sulfonate (A.B.S.) which is their active ingredient. Klein (1959) lists anionic detergents as the most common household type and it is likely that the method of analysis measured the greatest percentage of detergents present in the river.

Detergents do not occur naturally in river waters and were not found at Station I except on one occasion (Aug. 12, 1965) when a concentration of 0.003 p.p.m. was detected. It is likely that this value was from experimental error rather than the addition of A.B.S. upstream.

The average concentration at the various stations is shown in Fig. 30. Detergents entered the river from the sewage treatment plants and from Chemcell Ltd. The highest concentration found was at Station III-S on July 12, 1965 when 0.164 p.p.m. A.B.S. was detected. It is very likely that much higher concentrations would be found at this location during the low flows of winter. By Station VI the detergents have been absorbed until only an average concentration of 0.002 p.p.m. remains.

Although the toxicity of detergents is greatly modified by the chemistry of the receiving water the maximum concentrations found in the river were much less than the lethal concentrations found for even the most sensitive bottom organisms and fish by Hynes and Robert (1962) and Henderson et al. (1959).

21. Chemistry of Tributaries:

Table VI lists the water analysis results from Whitemud Creek and the Sturgeon River. At both tributaries the samples were taken near the mouth in running water. There is an indication of seasonal variations in many of the components. With the exception of sulphates, chlorides, and perhaps some of the minor metallic ions in Whitemud Creek, there was no great difference between the water chemistry of the tributaries and that of the main river.

Figure 30. Regional variation in synthetic
detergents.

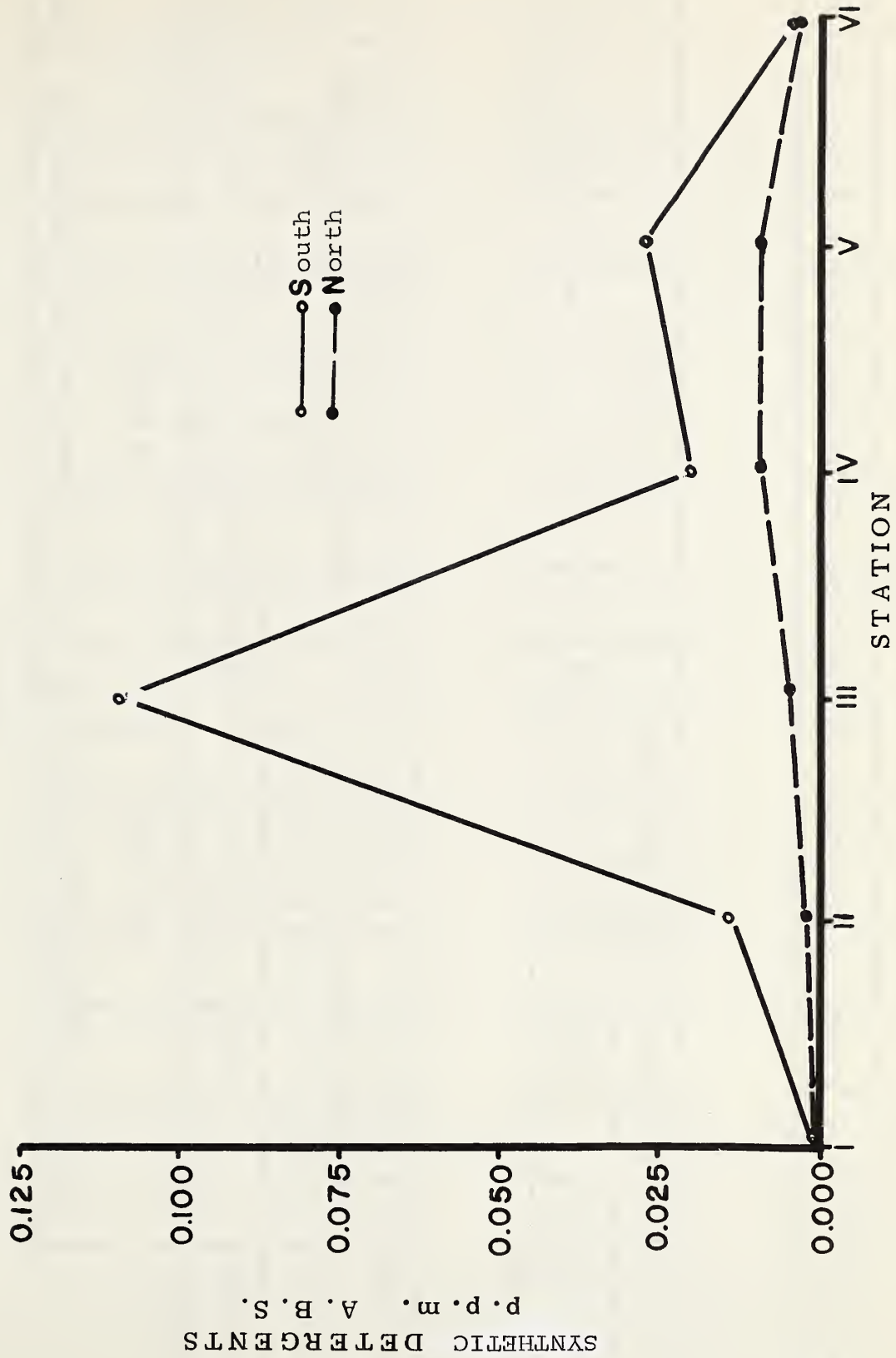


Table VI.

Chemistry of Whitemud Creek and Sturgeon River.

p. p. m.

Sturgeon River	pH	NO ₃	NO ₂	NH ₃	Alkalinity		Cl	Cr	Cu	F	Hardness		Fe	Mn	PO ₄	Si	SO ₄
					pp.	MO					Ca	Mg					
Sept. 18, 1964.	-	-	0.003	-	3.5	171	10	0.02	0.26	0.38	141	101	0.15	0	0.38	2.3	210
May 14, 1965	8.1	1.05	0.013	0.36	20	130	18	-	-	-	100	30	-	-	0.65	-	450
June 8, 1965	8.4	0.05	0.006	-	8.0	198	6.8	0.10	0.22	0.08	140	65	0.21	0.10	0.25	4.3	90

Whitemud Creek

Sept. 21, 1964	8.0	-	0.002	-	3.5	183	18	0.85	0.84	0.41	172	79	0.06	0.15	0.25	8.6	265
May 18, 1965	8.6	1.35	0.013	0.40	10	185	30	-	-	-	155	50	-	-	0.47	-	140

Station I

Sept. 21, 1964	8.3	-	0.003	-	3.5	137	6.8	0.04	0.45	0.31	114	47	0.04	0	0.35	6.2	47
May 19, 1965	8.2	-	0.008	0.15	15	152	4.5	0.11	0.25	0.13	122	48	0.24	0.3	0.17	4.5	39

VII. SUBSTRATE ANALYSIS

1. Chemistry:

Table VII lists the average concentrations found from analysis of mud samples taken from the various stations. Although the number of analyses was small (12), they do yield useful information. Nitrogen remains quite stable at all sampling sites except Station V where there was a decrease which was most noticeable near the south bank. This decrease in substrate nitrogen is surprising as there was a downstream increase in soluble nitrogen compounds (p. 59).

Phosphorus compounds appear to have been added from the effluent of the main sewage treatment plant and these elevated the substrate concentration, especially near the south shore.

Potassium showed a unique distribution in that the concentration was lowest below the two sewage treatment plants. There was a significant increase at Station V-S which was the product of the effluent from Chemcell Ltd. This effluent was also responsible for the increase in conductivity at Station V-S.

Sodium and sulphates were not detected in any of the analyses, although sulphates are a major anion in the river water.

Chloride displayed an interesting distribution in that it was only found in trace amounts near the south shore in the zone of effluent addition while it was somewhat more abundant near the north bank in the same region and most abundant in the clean water zone.

Table VII. Average Bottom Mud Analyses.

Station	Nitrogen ----- pounds per acre	Phosphorus ----- pounds per acre	Potassium ----- pH	Conductivity mmho	Sulphates ppm	Chlorides ppm	Sodium ppm	
I	6.5	3.0	123.0	8.2	0.55	0	20	0
II-S	6.5	5.0	75.0	8.3	0.40	0	20	0
III-N	6.5	9.0	130.0	8.1	0.60	0	-	0
III-S	6.5	25.0	69.0	8.25	0.45	0	T	0
IV-N	6.5	6.0	111.0	8.35	0.45	0	5	0
IV-S	6.5	18.0	120.0	8.2	0.60	0	-	-
V-N	5.5	4.0	110.0	8.2	0.50	0	-	-
V-S	4.5	10.0	169.0	8.05	0.85	0	T	0

T -- trace

- -- not determined

The substrate pH showed some variation about an average of 8.20, but was consistently lower at Station V-S.

The most noteworthy aspect of substrate analyses were the great differences which existed between them and the chemical analyses of the water. Burrowing bottom organisms, such as chironomids and oligochaetes, live in an environment which is chemically very different from that of the water column. Many authors (Beak, 1958; Caspers, 1954; Dvihally and Kozma, 1960; Gaufin, 1958; Moyle, 1956; Patrick, 1949, 1962; Powers, 1920; Richardson, 1921, 1928) base their conclusions about the chemical environmental requirements and preferences of the organisms on the chemistry of the water column. The microenvironment at the mud-water interface is very difficult to measure but it is likely to be intermediate between the conditions existing in the mud and those found in the water column.

2. Organic Matter:

The determinations of the percent organic material contained in sand and mud substrates showed a very large variation which existed even in samples taken within an area of a few square feet. The total amount of organic material in the mud was low as the maximum range was only from 0.62 - 6.70% as compared to the range of 14.3 - 47.0% found by Kerekes (1965) for a series of lakes near Edmonton.

Table VIII lists the average value found at each station, as well as the number of determinations and the range.

Table VIII. Substrate Organic Matter.

Station	Average % organic matter	Number of determinations	Range
I	2.03	4	1.29-2.55
II-N	4.05	1	
II-S	1.55	1	
III-N	1.70	1	
III-S	0.94	2	0.62-1.25
IV-N	1.70	1	
IV-S	0.88	2	0.79-0.96
V-N	0.93	2	0.91-0.95
V-S	4.93	4	2.80-6.70

The great variability and the limited number of determinations limits the usefulness of these data but it is apparent that there was no build-up of sewage sludge below the sewage treatment plants, at least during the summer when these determinations were made. This was due to the strength of the current which prevented the accumulation of sewage solids over a mud or sand bottom. The high values at Station V-S were a product of a reduced current in the immediate vicinity of the sampling site. As shown by the B.O.D. determinations (p. 49) there was perhaps some build up of organic sludge during the low flows of winter.

When the various stations were examined for bottom fauna with a Surber sampler, or several rocks were collected for periphyton enumeration, it was obvious that organic solids

were trapped in the interstices between the rocks and gravel. This was most noticeable near the south shore from Station II to Station V. This trapped material has an effect on the biota as will be shown in the discussion of the bottom fauna (p.103).

VIII. BIOLOGICAL CHARACTERISTICS

1. Plankton:

Fjerdingsstad (1964), Butcher (1932), Trembley (1962) and Wurtz (1955) have stated that floating organisms in rapid streams are not true plankters but members of a periphytonic community which have been dislodged from the substrate. Reid (1961) has used the term tychoplankton for these drift organisms. In 1964 this floating assemblage was sampled in the North Saskatchewan River and it was found that the algal forms present were in fact members of the periphyton, often still attached to small pieces of debris. The scouring effect of a sudden increase in river flow increased the numbers of organisms per litre of water. Scouring seems to be accomplished by the initial rise in flow, as a continued rise does not result in an increase in tychoplankton density. In a study of this sort it must be remembered that the number of organisms per litre of water is a poor measure as an increase in flow of 100% and a decrease in tychoplankton density of 50% would still maintain the same absolute numbers of plankters. The highest density found was 4,100 organisms per litre, which was associated with a sudden increase in flow. The average density throughout the year was approximately 500 per litre. Lackey (1941) found that there was only an average of 67.4 individuals per litre in the Missouri River which he believes is a result of high turbidity, high current velocity, and a lack of adjoining lentic environments.

The drifting organisms were carried some distance by the

current so there was no difference in the species composition or abundance at the different stations.

From late May until early July there seemed to be an extra abundance of Asterionella and Pediastrum but none of the other species showed any great seasonal fluctuation.

Due to the importance of the initial scouring effect in loosening organisms from the substrate, there was no correlation between organism density and flow.

During the summer of 1965 the washings from rocks collected at various stations were examined. Table IX lists the forms found by both this and the previous method.

Table IX. Algae of the North Saskatchewan River.

Diatoms:

Navicula sp.
Fragilaria sp.
Synedra sp.
Asterionella sp.

Green algae:

Stigeoclonium sp.
Pediastrum sp.
Spirogyra spp.
Scenedesmus spp.
Ulothrix sp.

Blue-green algae:

Oscillatoria angustissima

Flagellates:

Euglena viridis
Phacus pleuronectes

In addition a very few specimens of unidentified nematodes, rotifers, water mites and cladocerans were observed. In the North Saskatchewan River the ratio of 'phytoplankton' to 'zooplankton' (1000:1) is much greater than the ratios given for other large rivers by Berner (1951), 65:35, Missouri River; Kofoid (1908), 5:1, Illinois River; and Allen (1920), 9:1, San Joaquin River.

The qualitative results yielded by rock washings in 1965 suggest that Stations I and II on the south bank and Stations I - V on the north bank had essentially identical periphyton. All the listed forms were found at all these stations with the exception of Spirogyra which occurred only at Station VI. The rocks appeared quite clean, but when the washings were examined microscopically there was observed a rather dense population of plankters.

At Stations III - V near the south shore the rocks were covered with what appeared to be a dense mat of filamentous algae. On examination this was found to be composed of organic sewage debris. Living on or in this mat were found the same species as found elsewhere but in greatly reduced numbers. There was a form of colorless ciliate which was found in great numbers in association with this organic mat. At Station V-S, a washing of five small rocks taken in the area of this organic mat had to be diluted to 37.5 litres with distilled water until the sewage smell became too faint to recognize.

At Station VI there were found extensive mats of almost pure Spirogyra. These mats are thought to have been a

result of the increase in soluble nitrates and phosphates and the decrease in settled organic matter. The mats support a rich bottom fauna (p. 101). Oliff (1963) has observed the same increase in Spirogyra spp. and bottom fauna as a result of mineral pollution by phosphates and nitrates. Brinley (1942) has shown a negative correlation of periphyton and B.O.D. As one passes downstream to a point where the B.O.D. drops, there is a marked increase in certain algal forms, which is regarded as being a result of the fertilizing effects, but is probably also in part due to the decrease in settleable organic solids.

European workers as quoted by Hynes (1961) recognize the same zone in organically enriched rivers on the continent, but there the predominant alga is Cladophora.

In keeping with the present trend in pollution biology Spirogyra spp. could be termed an indicator genus in the North Saskatchewan River. I have some misgivings about the whole concept of indicator organisms. The conditions existing in an environment must be very well understood before an organism can be labeled as an indicator. Because this organism is indicative of one situation is no assurance that its abundance elsewhere is a result of the same conditions or that it will be found in a different part of the same river having the required chemical and physical characteristics. As chemical, physical and biological conditions differ greatly from one river to another, it seems unrealistic to suppose that the same equilibrium between any organism and its environment

exists in two different rivers.

The North Saskatchewan River has the potential to form extensive algal blooms. A one-litre sample of water collected at Vinca Ferry on March 10, 1965 was stored in a refrigerator until April 17. At that time the concentration of algae was negligible, only one or two cells being found in one ml. The litre sample was diluted to eight litres with city tap water and placed in a large sealed glass container near a window. By April 27 there was an extensive green mat covering the bottom of the container. The sides of the glass jar remained relatively free of plankton growths. There was no visible sign of plankters suspended in the water.

2. Bottom Fauna:

a. Qualitative composition:

The bottom fauna of the North Saskatchewan River can be divided crudely into two groupings: those species which inhabit the gravel reaches and those found in or on a mud or sand substrate. The organisms collected and the substrate type on which they were most abundant are tabulated in Table X.

The mud and sand community was composed almost entirely of chironomids and oligochaetes. One dredge sample at Station I contained the mayfly Ephemerella invaria and a single snail specimen of the genus Menetus, while one dredging at Station II-N contained two specimens of the dipteran Atherix sp. The chironomid fauna consisted of the sub-families Chironominae, Orthocladiinae and Diamesinae containing 2, 4, and 1 species respectively. The genera Tubifex and

Table X. Bottom Fauna Organisms of the North Saskatchewan River.

Diptera

Family Tendipedidae

Subfamily	Chironominae	Mud
	Orthocladiinae	Mud
	Diamesinae	Mud

Family Rhagionidae

<u>Atherix</u> sp.	Gravel
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Ephemeroptera

<u>Rhithrogena</u> sp.	Gravel
<u>Ephemerella invaria</u>	Gravel

Odonata

<u>Ophiogomphus severus</u>	Gravel
-----------------------------	--------

Plecoptera

<u>Acroneuria</u> sp.	Gravel
<u>Isogenus frontalis</u>	Gravel
<u>Pteronarcys dorsata</u>	Gravel
<u>Hastaperla brevis</u>	Gravel

Trichoptera

<u>Brachycentrus</u> sp.	Gravel
<u>Hydropsyche recurvata</u>	Gravel

Hemiptera

<u>Collicorixa audeni</u>	Gravel and Mud
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Amphipoda

<u>Gammarus lacustris</u>	Gravel
<u>Hyalella azteca</u>	Gravel

Oligochaeta

<u>Limnodrilus hoffmeisteri</u>	Mud
<u>Limnodrilus udekemianus</u>	Mud
<u>Limnodrilus claparedeanus</u>	Mud
<u>Limnodrilus profundicola</u>	Mud
<u>Tubifex tubifex</u>	Mud
<u>Nais elinguis</u>	Mud

Gastropoda

<u>Ferrissia</u> sp.	Gravel
<u>Lymnaea palustris</u>	Algae beds
<u>Physa heterostropha</u>	Algae beds
<u>Menetus</u> sp.	

Limnodrilus were the dominant oligochaetes. A few specimens of Nais elinguis were also collected.

Dredgings taken from a sand bottom showed a paucity of organisms which is in accordance with the findings of Reed (1962) and Gaufin (1955).

Surber samples taken from gravel and rubble bottoms yielded the same forms of chironomids and oligochaetes but in smaller numbers than taken from mud bottoms. Isogenus frontalis was the most abundant plecopteran but Pteronarcys dorsata, Acroneuria sp. and Hastaperla brevis were also found. Two ephemeropterans, Rhithrogena sp. and Ephemerella invaria, were common while the order Odonata was only represented by a few specimens of Ophiogomphus severus. The caseless trichopteran, Hydropsyche recurvata, was common and Brachycentrus sp. was found.

The hemipteran, Collicorixa audeni was occasionally very abundant at most stations but was never observed or collected near the south bank from Station III to V which is different from the findings of Gaufin and Tarzwell (1952) who found this genus common in regions of organic enrichment. The coleopteran, Elmis sp., was found in one sample taken at Station II-N and one at Station VI.

At Station VI the fresh water limpet Ferrissia sp. was abundant as was another gastropod, Physa heterostropha. The fact that these forms were never found elsewhere suggests that their presence was due to the beds of filamentous algae at Station VI. At this same station the species

Lymnaea palustris was also found. Within two hundred meters of the mouth of the Sturgeon River the North Saskatchewan River had a fauna which was partly derived from this tributary. Here the amphipods Gammarus lacustris and Hyalella azteca were common.

Slightly upstream from its confluence with the North Saskatchewan River the Sturgeon River was found to contain three species of large bivalve molluscs (Anodonta grandis, Lampsilis luteola, Lasmigona complanata) but these were not found in the main river. One of these species (A. grandis) was also found in Whitemud Creek. Leeches were also abundant in the Sturgeon River but were never taken elsewhere in the study area. In the spring of 1965 the Sturgeon River flooded as a result of the above average snowfall of the previous winter. This swept large numbers of organisms out onto the ice of the North Saskatchewan River where they were easily collected. It was observed that the fauna of the Sturgeon River was different from that of the North Saskatchewan River, especially with respect to the caddis flies. It is thought that the forms found in the North Saskatchewan River are capable of withstanding a swift current, and indeed may require swift water. The inhabitants of the normally sluggish Sturgeon River are adapted for that type of existence and could not retain their position in an increased current.

The number of genera of macro-invertebrates (25) found in the North Saskatchewan River is much smaller than the 122 genera found by Gaufin (1958) in the Mad River in Ohio.

However, in the clean water section of the Mad River no species exceeded a population density of 25 per square yard while in the same section of the North Saskatchewan River many of the more common forms exceed this number. Gaufin (1958) does not present total weights or numbers for comparison but it seems possible that the paucity of species in the North Saskatchewan River is compensated for, at least in part, by an increase in population density.

b. Quantitative composition:

In this study it was decided to deal with weights of organisms rather than with total numbers as this seems to have several advantages. First, it gives a more accurate idea of the bottom fauna production as, for example, one mayfly weighs as much as several oligochaetes. A numerical approach would make it appear that the oligochaetes would be the predominant group although in terms of fish food availability or biomass, the single mayfly could be of equal importance. Second, it is much easier to plot a variation of 0 - 29 grams per square meter than it is to plot a range of 0 - 16,800 individuals per square meter which are the ranges of weights and numbers of oligochaetes found in this study. There is one drawback to the system in that some of the very large forms, such as certain stoneflies which were only taken occasionally in samples, yield a calculated weight per square meter far in excess of the actual weight. However, if expressed in numbers per unit area, the result would be just as inaccurate.

Table XI lists the range in the numbers of individuals

Table XI. Abundance of Bottom Fauna Organisms.

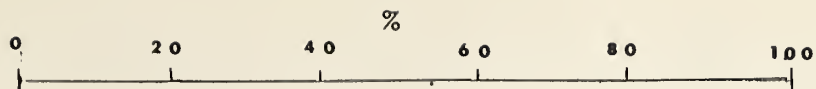
Organisms	Range (individuals per square meter)
Chironomidae	8.6(IV-S) - 989(VI)
Oligochaeta	25.9(I-N) - 16800(VI)
Plecoptera	
<u>Isogenus frontalis</u>	0.0(III-S-V-S) - 62(VI)
<u>Pteronarcys dorsata</u>	0.0(III-S-V-S) - 2(I-S)
<u>Acroneuria</u> sp.	0.0(III-S-V-S) - 1(I-S)
<u>Hastaperla brevis</u>	0.0(III-S-V-S) - 108(I-S)
Ephemeroptera	
<u>Rhithrogena</u> sp.	0.0(III-S-V-S) - 27(IV-N)
<u>Ephemerella invaria</u>	0.0(III-S-V-S) - 15(I-S)
Trichoptera	
<u>Hydropsyche recurvata</u>	0.0(III-S-V-S) - 130(III-N)
<u>Brachycentrus</u> sp.	0.0(III-S-V-S) - 5(VI)

per square meter of some of the predominant forms based on the averages for each station.

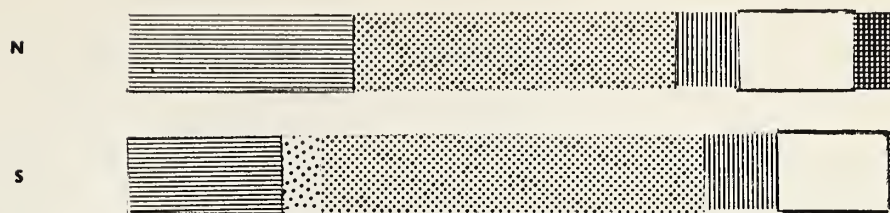
As shown in Fig. 31 the fauna of the clean water section, represented by Station I, was a diverse one in which chironomids and stoneflies predominate in terms of percent of the total weight. This situation was maintained on the north side of the river at Stations II and III although the caddis flies became increasingly abundant as well. The addition of treated domestic sewage below Station I resulted in an increase in the chironomids and oligochaetes near the south bank, but did not adversely affect the other groups. The entrance of the effluent from the main sewage treatment plant on the south bank above Station III-S resulted in a depression of the chironomids and a great increase in oligochaetes while all other forms were excluded completely. This situation existed near the south shore down to, and including, Station V. At Station IV there seemed to be some mixing of the sewage wastes with the water near the north shore as there was an increase in oligochaetes at this site. At Station VI, which is far enough downstream for complete mixing of all effluents to have taken place, both shores of the river possessed near-identical faunas and thus are treated as one. The oligochaetes predominated, but all other groups were present.

Figs. 32 - 36 show the weights of each major group of organisms at the different stations. These show that mayflies, stoneflies and caddis flies were excluded from Station III to V near the south bank. With the exception

Figure 31. Relative abundance of bottom fauna
within the study area.



Station I



Station II



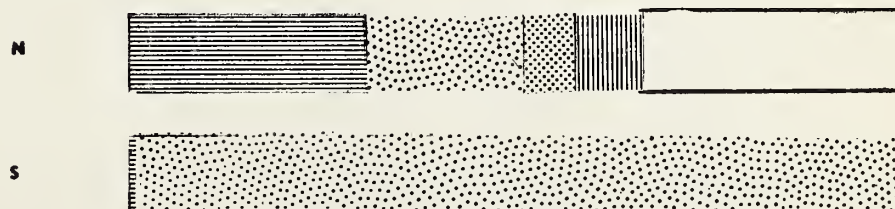
Station III



Station IV



Station V



Station VI



Chironomids



Mayflies



Caddis flies



Oligochaetes



Stoneflies



Miscellaneous

Figure 32. Regional variation in mayfly biomass.

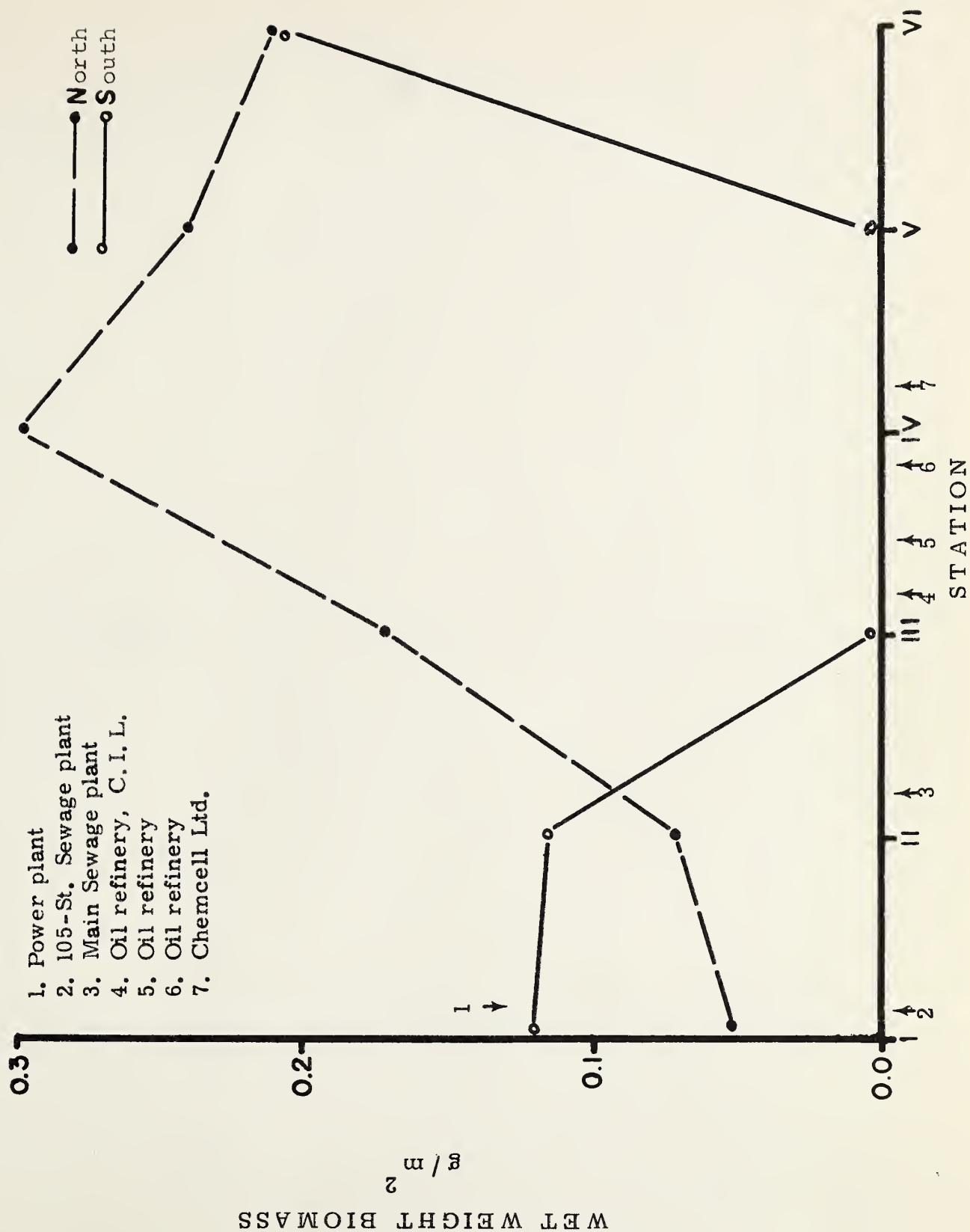


Figure 33. Regional variation in stonefly biomass.

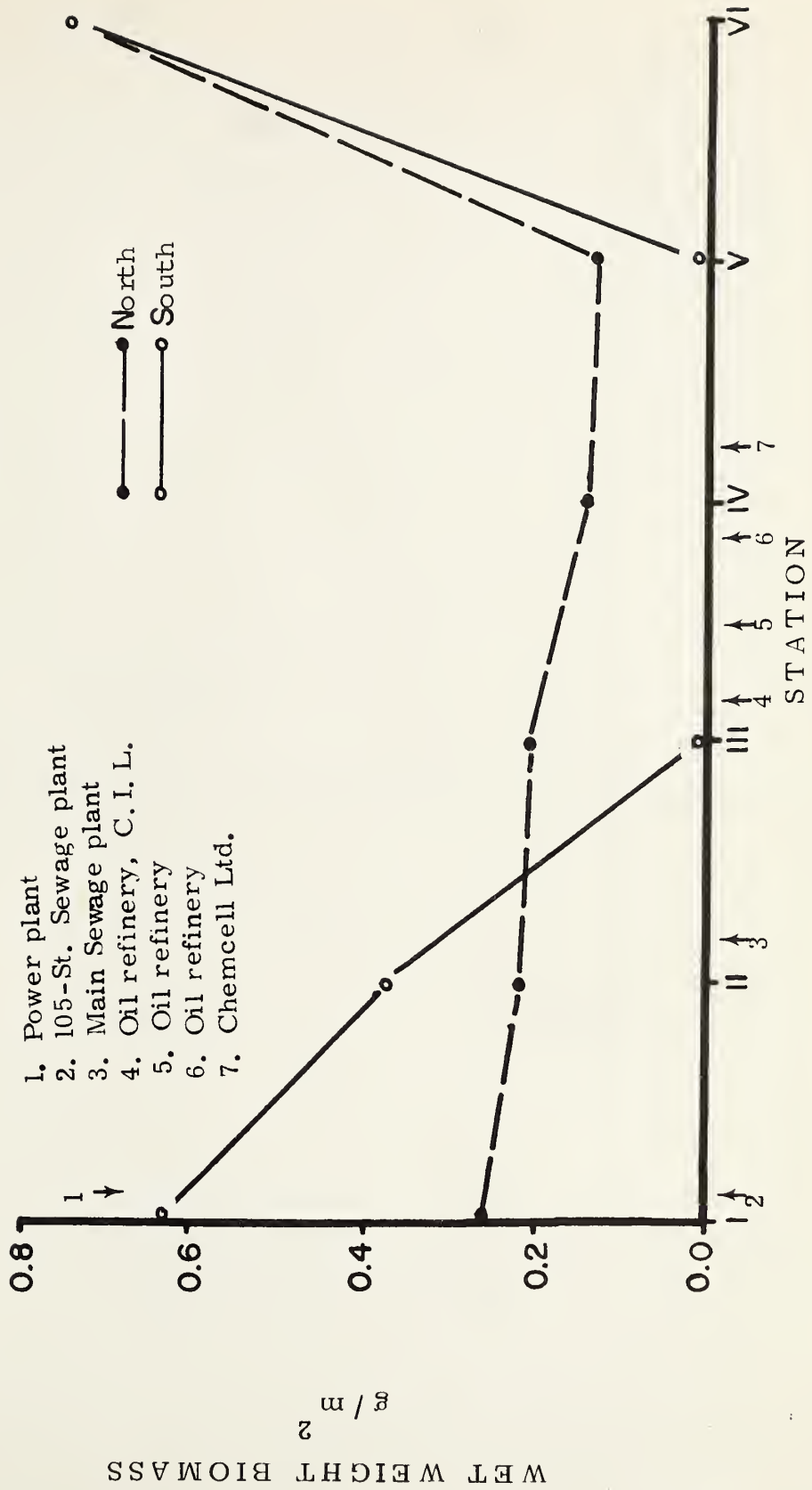
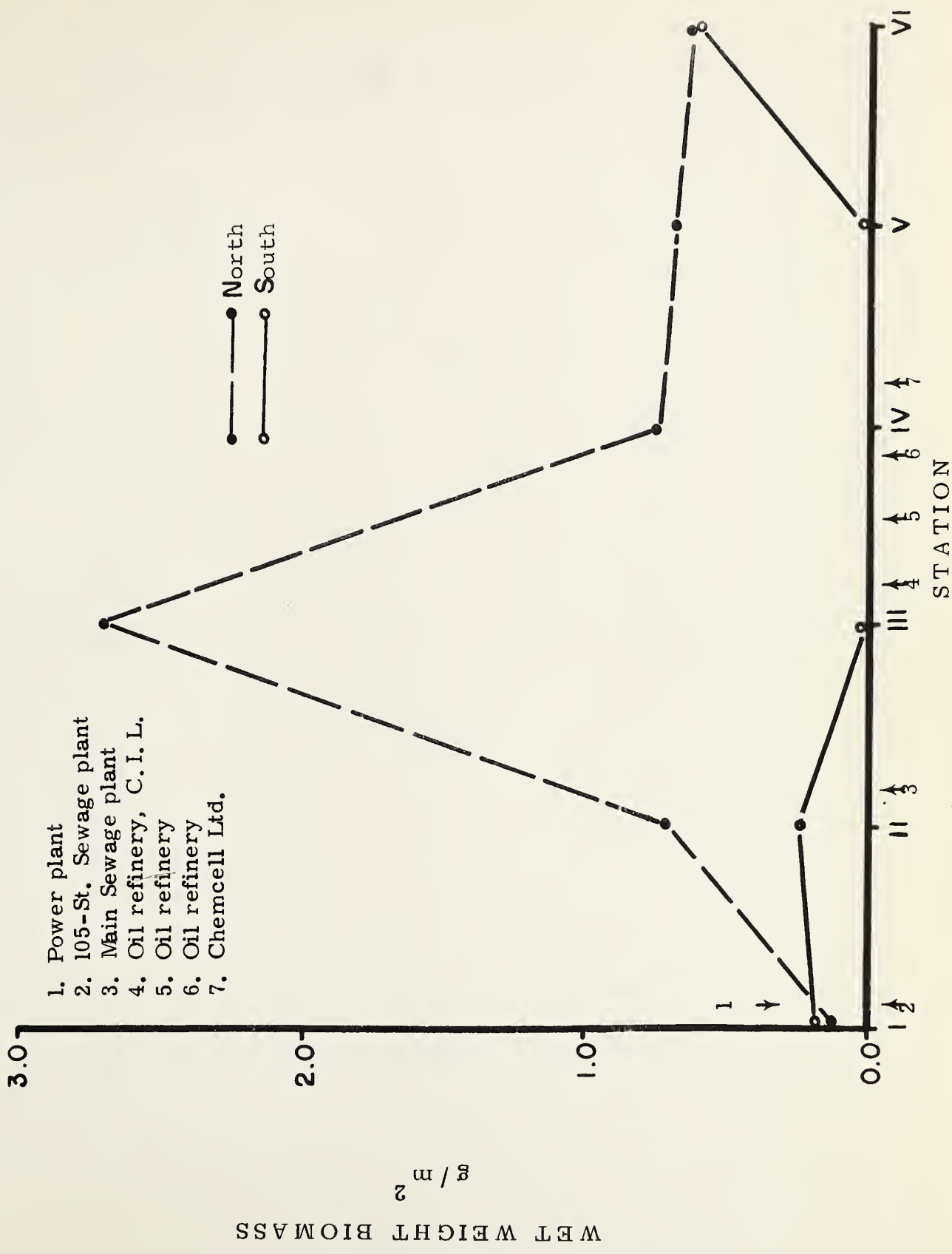


Figure 34. Regional variation in caddis fly biomass.



1. Power plant
2. 105-St. Sewage plant
3. Main Sewage plant
4. Oil refinery, C.I. L.
5. Oil refinery
6. Oil refinery
7. Chemcell Ltd.

Figure 35. Regional variation in chironomid biomass.

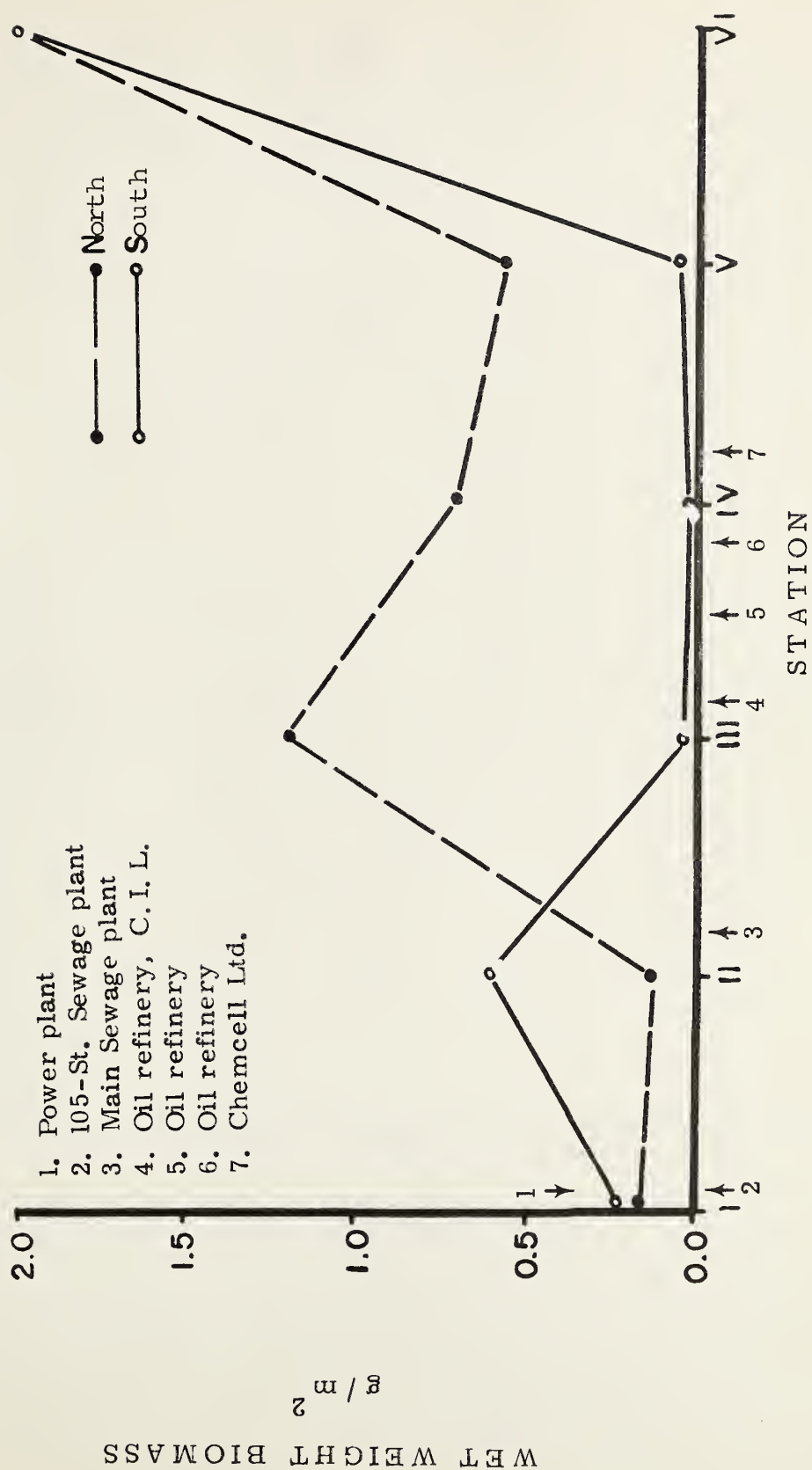
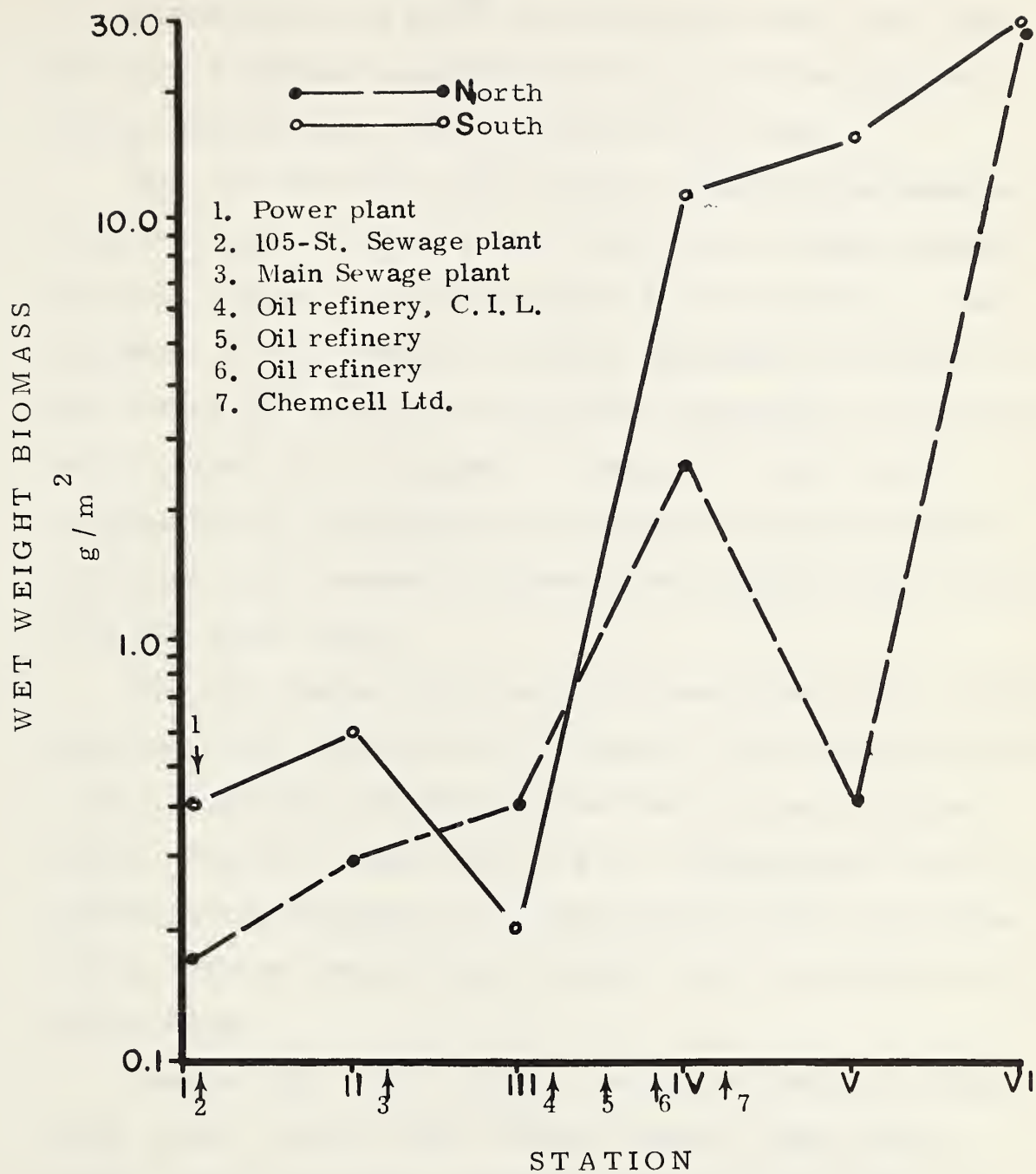


Figure 36. Regional variation in oligochaete biomass.



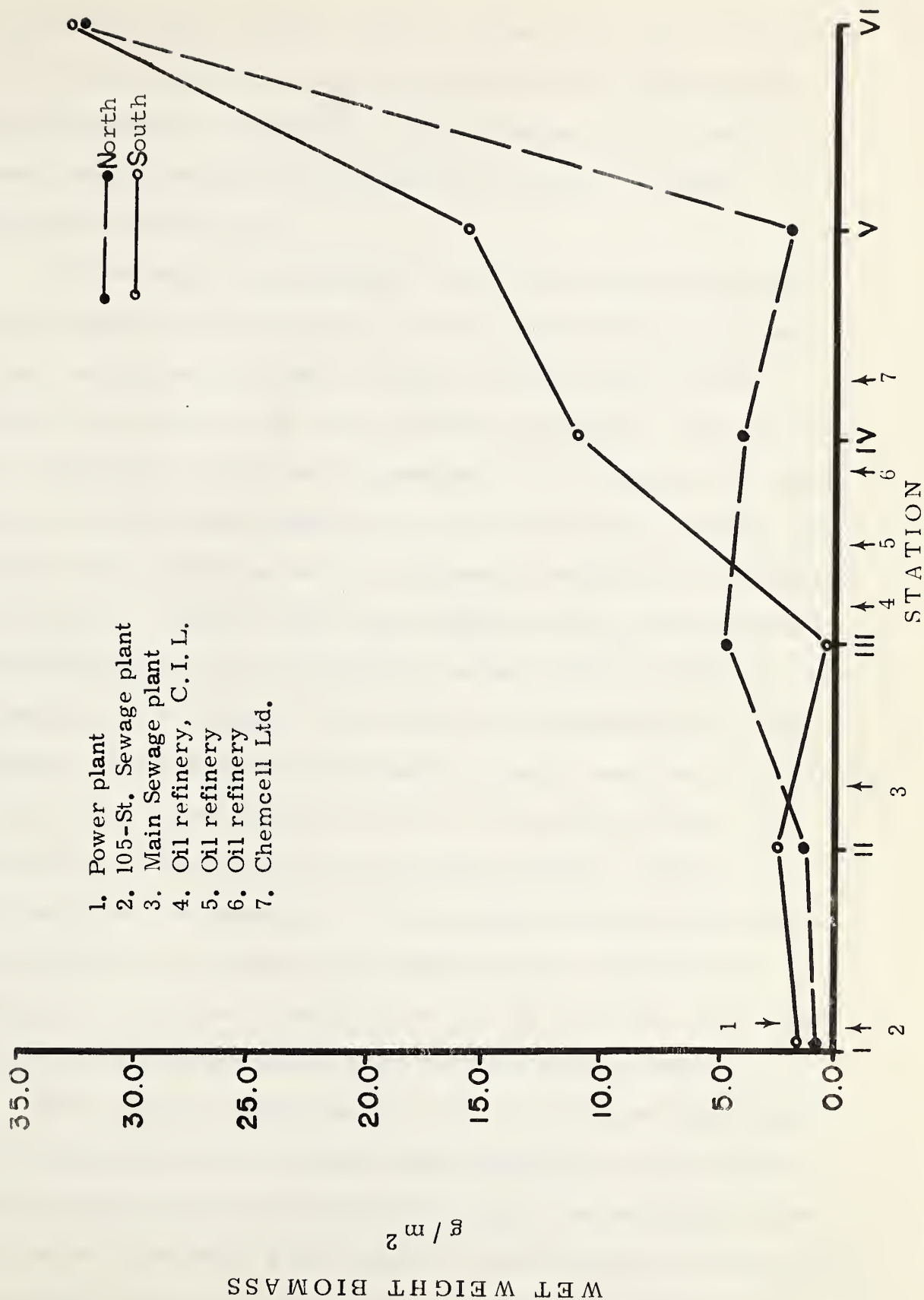
of stoneflies which showed a decrease, the same forms increased in abundance near the north shore. Although chironomids were not restricted from this same zone, they did show a decrease near the south shore while the north shore became richer than the clean water zone.

Fig. 37 shows the total weight of macro-invertebrates at each station. This shows that there was a steady increase in total bottom fauna from Station I to Station VI. The increase in total weight of bottom organisms at Station VI was due to the increase in dissolved phosphates and nitrates, which caused the development of extensive algal beds, accompanied by a decrease in the amount of large organic particles which tended to blanket the substrate near Station V on the south shore.

The few samples which were obtained from points further down the river from Station VI suggest that the trend towards a more productive bottom continued for at least 15 more miles. However, these data were not incorporated into the present study because of the complicating factor of rather poorly treated sewage being released into the river at Fort Saskatchewan.

Gauvin (1955, 1957, 1958), Gauvin and Tarzwell (1952, 1955, 1956), Ingram (1957, 1959), Patrick (1949, 1957), Surber (1953) and Wurtz (1955) have described studies in which stoneflies, mayflies and caddis flies are eradicated from those parts of water courses receiving domestic sewage effluents. Several of these authors attribute this to the inability of the organisms to live in water which has a low

Figure 37. Regional variation in total bottom
fauna biomass.



dissolved oxygen content which is often the result of adding high B.O.D. wastes to slow flowing streams. Chironomids and oligochaetes, which can live in water with a much lower oxygen content, can thrive as a result of the decreased competition.

In the North Saskatchewan River the dissolved oxygen never dropped below 7 p.p.m. in the area devoid of stoneflies, mayflies and caddis flies so this cannot be the controlling factor, at least in this situation. Nor can it be competition with the oligochaetes as at Station VI there were well-developed communities of stoneflies, mayflies and caddis flies existing with oligochaete population in excess of 28 g/m^2 . Roback (1962) has described the environmental requirements of the Trichoptera as has Gauvin (1962) for the Plecoptera and Leonard (1962) for the Ephemeroptera. The chemical and physical environment present near the south shore of the river from Station III to V falls well within the limits of tolerance listed by these authors. Perhaps it is some organic component of the sewage which cannot be tolerated by the stoneflies, mayflies and caddis flies, or it may be a physical restriction due to the filling of the interstices between rocks with organic sewage debris.

That certain effluents are toxic to bottom organisms, or in some other way exclude them completely, was evident from samples obtained immediately below the effluent. The city water treatment plant empties large amounts of insoluble carbonates into the river which immediately settle to the bottom. For approximately 100 meters downstream from the

effluent an Ekman dredge will sink for one meter into the white deposit. This reach was completely devoid of bottom fauna. Macro-invertebrates were also absent for less than 20 meters below the effluents from the oil refineries and Chemcell Ltd.

It will be noted that in the clean water zone the south shore had a richer fauna than the north shore. This is thought to be due, in part, to the influence of Whitemud Creek which discharged organic detritus into the river near the south shore during the spring runoff and heavy summer rains. Also at this latitude (53°N) the south banks of rivers have a dense covering of trees while the north bank supports a flora composed more of grasses and brush. The greater amount of plant detritus entering the river on the south shore favors a denser macro-invertebrate fauna (Egglshaw, 1964).

3. Fish Fauna:

During the course of this study a total of 21 species of fish were taken in the North Saskatchewan River and the Whitemud Creek and Sturgeon River tributaries (Table XII).

Two other species have been reported from the river in the Edmonton region (lake sturgeon, Acipenser fulvescens and quillback sucker, Carpionodes cyprinus). The northern redbelly dace, brook stickleback, and fathead minnow were only collected in Whitemud Creek. The latter two species were common there but the dace was only represented by one specimen. Perhaps it is a preference for quiet, slow moving

Table XII. Fish Fauna of the North Saskatchewan River.

Salmonidae

Prosopium williamsoni - Rocky Mountain whitefish

Salvelinus malma - Dolly Varden

Esocidae

Esox lucius - Northern pike

Hiodontidae

Hiodon alosoides - Goldeye

Cyprinidae

Chrosomus eos - Northern redbelly dace

Hybopsis gracilis - Flathead chub

Hybopsis plumbea - Lake chub

Notropis atherinoides - Emerald shiner

Notropis blennius - River shiner

Notropis hudsonius - Spottail shiner

Pimephales promelas - Fathead minnow

Rhinichthys cataractae - Longnose dace

Catostomidae

Catostomus catostomus - Longnose sucker

Catostomus commersoni - White sucker

Moxostoma macrolepidotum - Northern redhorse sucker

Gadidae

Lota lota - Burbot

Gasterosteidae

Eucalia inconstans - Brook stickleback

Percopsidae

Percopsis omiscomaycus - Trout perch

Percidae

Stizostedion canadense - Sauger

Stizostedion vitreum vitreum - Walleye

Cottidae

Cottus ricei - Spoonhead sculpin

water which prevents their entry into the North Saskatchewan River, but there does not seem to be any obvious reason why they were absent from the Sturgeon River which has very similar flow characteristics and water chemistry (p. 78). Whitemud Creek appears to be more favored by fish than the Sturgeon River; only the sculpin was not found there while five species were absent from the Sturgeon River.

Table XIII shows the distribution of fish taken by seining within the study area. Seining also yielded young of the northern pike, burbot, yellow walleye, and sauger but not in large enough numbers to allow generalizations to be made. It will suffice to say that none of these species were taken near the south side of the river at Stations III - V.

As can be seen from Table XIII, most small fish were excluded from the south shore of the river from Station III to Station V. The only specimens collected from several seine hauls in this region were two one-year old white suckers. Rasmussen (1955) and Pentelow et.al.(1938) have found that fish are often absent below organic sewage outfalls, although the oxygen content is well above their lower limit of tolerance and no toxic substances are present. On the north shore, Station III and Station IV had a more typical clean water fauna, but at Station V this became reduced. At Station VI there was a re-establishment of the population on both sides of the river.

Larger fish did not seem to be so affected in this zone. Anglers were as successful at Station V-N as anywhere

Table XIII.

Distribution of Fish in the Study Area

Species	I		II		III		IV		V		VI	S	W
	N	S	N	S	N	S	N	S	N	S			
Lake chub	***	***	***	***	**	-	**	-	*	-	P	**	***
Flathead chub	**	**	**	**	*	-	**	-	**	-	-	-	**
Emerald shiner	**	**	**	**	*	-	*	-	*	-	**	-	*
Spottail shiner	P	P	-	-	P	-	-	-	-	-	-	-	*
River shiner	**	**	**	**	**	-	**	-	*	-	**	-	P
Fathead minnow	-	-	-	-	-	-	-	-	-	-	-	-	P
Longnose dace	**	**	**	**	**	-	**	-	*	-	***	***	*
Longnose sucker	*	*	*	*	*	-	*	-	*	-	*	*	*
White sucker	***	***	**	***	**	-	**	-	**	P	**	***	***
Redhorse sucker	-	-	-	-	-	-	-	-	-	-	*	P	P
Brook stickleback	-	-	-	-	-	-	-	-	-	-	-	-	**
Trout-perch	**	**	**	**	-	-	-	-	-	-	*	-	**
Spoonhead sculpin	P	P	P	P	P	-	-	-	-	-	P	-	-

*** - very abundant

** - abundant

* - common

P - present

W - Whitemud Creek

S - Sturgeon River

on the river. Large fish were observed jumping near the south shore between Station III and Station IV.

In the winters of 1961-1965 seining was carried out in the warm water immediately downstream from the Edmonton power station. On March 31, 1963 several Rocky Mountain whitefish were captured, which was the only occasion on which this species was taken. On the same date more fish were captured with a comparable amount of seining than at any other time. Perhaps under certain conditions of temperature and dissolved oxygen fish are attracted to this site. Trembley (1960, 1961) found that fish were attracted to warm effluents during the winter.

Although the sauger was only first reported from the river in 1961, the scanty data obtained on this species and the closely related yellow walleye would indicate that they are of near equal abundance in the river.

The only Dolly Varden observed during this study was a large specimen captured by an angler at Station I on May 4, 1965.

During the high water period of June and July, large fish seemed to congregate in the backwaters at the mouths of tributaries and old cut-off channels. As shown in Table XIV, these fish returned to the main river when the water level dropped in the late summer.

The goldeye was often taken by anglers in the river, especially in the period from late May to late July, but it was far from being the most abundant species in anglers creels. Adult goldeye were the most abundant fish in gill

Table XIV. Gill Net Sets in the North Saskatchewan River.

Sturgeon River	June 19, 1964	24 m. of net for 2 hrs.
	Goldeye	18
	Longnose sucker	1
	White sucker	15
	Redhorse sucker	1
	August 19, 1964	24 m. of net for 2 hrs.
	Longnose sucker	1
Whitemud Creek	July 6, 1964	24 m. of net for 2 hrs.
	Goldeye	9
	Northern pike	1
	Sauger	1
	Longnose sucker	1
	White sucker	1
	July 27, 1965	24 m. of net for 1 hr.
	Goldeye	1
Big Island	July 17, 1964	48 m. of net for 4 hrs.
	Goldeye	42
	Northern pike	2
	White sucker	1
	August 1, 1964	36 m. of net for 4 hrs.
	White sucker	8
	Redhorse sucker	2
	June 4, 1965	36 m. of net for 12 hrs.
	White sucker	1
	Longnose sucker	8
	July 17, 1965	48 m. of net for 4 hrs.
	Goldeye	1
	Northern pike	1
	White sucker	3

net catches, outnumbering all other species combined, thus indicating that they are more abundant than would be suggested from angling results. The length range of all goldeyes captured was 30.6 - 39.5 cm. with an age range of 4 - 9 years. Although in excess of 10,000 small fish have been seined from the river during this study, no goldeyes younger than 4 years have been captured. In 1964 goldeyes were first taken on June 19. It was found then that the gonads of all specimens were small and showed no obvious evidence of having finished spawning, although this possibility exists. Sprules (1947) found that the goldeyes in the Saskatchewan River in Manitoba entered marshy areas and spawned immediately after breakup in the spring and by August young goldeye, 6.3 cm. in length, were abundant in the river. There are no marshy areas near the study area in which this species could spawn and young of the species were most certainly not common, if present. As it is difficult to imagine the species maintaining such a large population by the immigration of adult, non-spawning fish, perhaps the adult fish are migrating into this region after spawning further downstream. There is no evidence for this suggestion except that fishermen never take the species before the last week in May, which is at least one month after breakup.

A comparison of the fish found in the study area provides some interesting comparisons with the list of species taken in the same river in Saskatchewan by Reed (1962). That author collected the quillback sucker which was not taken in the present study, but seven species

collected in the North Saskatchewan River near Edmonton were absent from the same system in Saskatchewan. Two of these, the Dolly Varden and Rocky Mountain whitefish, were absent because their range does not extend that far east. The spottail minnow was not found in any part of the Saskatchewan drainage system in Saskatchewan. The lake chub, emerald shiner, river shiner and sauger are interesting as they were, with the exception of the sauger, abundant in the Edmonton area, and the South Saskatchewan and Saskatchewan Rivers in Saskatchewan but were not found in the North Saskatchewan River in that province. Perhaps they were excluded from that section of the system as a result of the severe pollution of the early 1950's (p. 20) and have not become re-established.

Reed also reported that sturgeon were common in the North Saskatchewan River twenty or thirty years ago, which is in keeping with the reports received from power plant personnel, where the species was once often trapped against the intake screens. Older fishermen along the river near Edmonton also state that sturgeon were once much more common.

IX. DISCUSSION

In any large river, such as the North Saskatchewan, the origin and the volume of the water can change very rapidly. For this reason chemical, physical, and to a lesser extent biological, characteristics of the river show variations which are the product of these rapid changes.

Turbidity and suspended solids are directly correlated with flow, while many chemical components show an inverse relationship with flow because rain and melt water tend to dilute the existing concentration in the river water. Water, when it freezes, loses much of its load of dissolved materials and thus the concentration of these materials increases in the unfrozen water column in the winter when the flow is small.

Nitrite nitrogen and chloride ion show a positive correlation with flow. This is thought to be a result of additions, perhaps from upstream tributaries with a substrate rich in these substances, which would be added to the river in proportion to the flows in these tributaries. Phosphate also shows a decrease in winter when the flow is at a minimum, but this is due to the unique ability of ice to concentrate this compound.

Such noticeable seasonal changes in biological characteristics are not to be found. As many aquatic organisms have life cycles which transect the various chemical and physical cycles of the water, these organisms must be able to cope with these changes in order to survive. Thus, the faunas of the North Saskatchewan and Sturgeon Rivers differ

because the organisms in each are adapted to different ranges of environmental conditions. When the Sturgeon River flooded in the spring of 1965, some parameter extended beyond its normal range and the organisms suffered. This perhaps lends strength to the argument that where there is a wide range in physical and chemical conditions a few biological samples obtained at any time of the year can be more useful in elucidating these conditions than can water analyses even if done at various times of the year. This is very true in the North Saskatchewan River below Edmonton.

When a river is used for waste disposal, as is the case at Edmonton, the wide range in conditions found in the receiving water makes it difficult, if not impossible, to predict the effect of effluents on the biota of the river. Due to the great dilution of all wastes, there was never found to be a general increase in any compound to a level which would be toxic to the species present in the river. Thus, a consideration of only physical and chemical data would indicate that little, if any, changes in the flora and fauna would occur because of modifications in the river brought about at Edmonton. The fact that marked changes in biota did occur, suggests that factors which are not readily apparent from water analyses do have an important effect. These include such things as slight increases in nutrients, modification of the substrate, or the increase in a chemical compound to a level which, although not lethal, causes the organisms to abandon the affected zone. Also there are certain parameters, such as ammonia nitrogen,

B.O.D., and water temperature, which are known to be detrimental or lethal to aquatic organisms if the level increases significantly. However, it is often found, as in this study, that small increases are advantageous.

There is also the problem that the results obtained from chemical analysis of a sample only measure the conditions existing at the sampling point during the very brief period when the sample was actually being obtained. The real conditions in the river below the point of entry of an effluent depend upon the diurnal variation in the production of the effluent, periodic or irregular shut-downs, and a vast array of other industrial variables. Biological samples obtained from the same site give a measure of the worst conditions which have prevailed for a period equal to the life span of the organisms encountered. As Tarzwell (1962) has so logically explained, there are no types of pollution, with the possible exception of radioactive wastes, which can greatly modify the receiving water and yet have no detectable effect on the organisms living within this water.

Pollution investigations have long been the realm of the sanitary engineer whose raw data are entirely chemical and physical. Consequently there have been many attempts to establish lethal levels of various pollutants for fish and bottom fauna in order that these data may be used to predict biological effects (Tarzwell, 1962; Smith, 1955; Huet, 1962; Beak, 1958; Moore, 1942; Young, 1923; Vernon, 1954; Doudoroff and Katz, 1950, 1953). Perhaps besides the

biochemistry and biophysics of pollution, there is another aspect, that of pollution ethology. Hasler and Wisby (1949) have shown that certain fish can detect, and will move away from, a phenol concentration as small as 0.005 p.p.m. Motile organisms such as fish and some of the larger macro-invertebrates may well be absent, by choice, from a zone in which the chemistry and physics are not lethal to the organisms.

In natural water courses there is a wide spectrum of conditions ranging from the oligotrophic state to one which is highly eutrophic. The process of eutrophication initially increases the number of species and the biomass. As the process continues the biomass increases further, but the numbers of species decline until only a few species of blue-green algae are present in great abundance, while other forms of aquatic life are reduced. If the optimal condition is defined by complexity and diversity of the food chain, then the optimum can be represented as a broad band near the middle of the spectrum of natural conditions. In the North Saskatchewan River the increase in numbers and types of macro-invertebrates at Station VI could well serve as an increased source of fish food and thus cause an increase in the fish fauna biomass. This being the case, the additions to, and the modifications of, the river brought about at Edmonton have a fertilization or eutrophication effect. This eutrophication may shift the conditions within the study area to a point nearer the center of the optimal band. The conditions are most certainly not shifted to an extent

which would be detrimental to the macro-invertebrate or fish communities.

This does not preclude the possibility that the addition of effluents at Fort Saskatchewan or an increase in the volume of wastes released at Edmonton could result in a decrease in the bottom fauna biomass. Nor is it suggested that the conditions prevailing in the study area at the present time are not detrimental to industrial, domestic, or agricultural uses of the river.

X. SUMMARY AND CONCLUSIONS

1. The flow of the North Saskatchewan River at Edmonton fluctuates over a wide range. During the study period the minimum flow was 1071 c.f.s and the maximum was 92,300 c.f.s.
2. Turbidity as well as nitrites, phosphates and chlorides are positively correlated with flow. Most other chemical components show a negative correlation.
3. The concentrations of many chemical compounds are increased by the addition of effluents at Edmonton. The modification of any component is never extensive enough to cause it to be lethal to aquatic organisms after the effluent becomes mixed with the river water.
4. The chemistry of the mud substrate shows little, if any, correlation with the chemistry of the water.
5. There is very little organic material contained in the mud as sewage solids are prevented from settling by the speed of the current. The interstices between rocks do trap organic solids.
6. Periphyton species composition is not greatly changed by effluent addition, but species abundance is changed. At Station VI the growth of mats of Spirogyra spp. is due to an increase in nutrient salts and a decrease in suspended and settled organic solids. There is no true plankton community in the river.
7. The immediate effect of effluents is to exclude stoneflies, mayflies and caddis flies and to favor oligochaetes.

8. At Station VI all bottom fauna types are present and the total wet weight biomass is greater than at Station I.
9. Fish are mostly absent near the south shore in the region of effluent addition. This absence is one of choice rather than the inability to survive there.
10. The effluents added to the river have an eutrophication effect as shown by the increase in macro-invertebrate bottom fauna.

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APPENDIX I. CHEMICAL ANALYSES.

Site	Date	Flow cfs	Temp. C°	pH	D.O. ppm	B.O.D. ppm	Alk. ppm	Cl ppm	Cr ppm	Cu ppm	F ppm	Station I. Hardness ppm		Fe ppm	Mn ppm	NH ₃ ppm	NO ₂ ppm	NO ₃ ppm	PO ₄ ppm	Si ppm	SO ₄ ppm	Phenols ppm	A.B.S. ppm	Turb. Jackson units	Cond. mmhos
												Ca	Mg												
S	May 27/64	7620		8.0	9.8	2.00				0.18						0.12									
M	June 1/64	6230	15.7				140	4.5		0.20		110	57	0.25						6.2					
M	June 4/64	19700	14.8	8.2	9.1	0.96																			
S	June 16/64	34500	12.1	8.3	9.6	1.17	100	7.5				85	37						0.17	3.8	24			600	183
S	June 24/64	34200	14.1	8.3	9.0	0.28	114	9.1				90	46						0.17		28			237	206
M	July 3/64	16600	17.0	8.2	8.6	0.96	140	7.0													30			57	260
M	July 13/64	23100	17.9	8.3	7.8		93	6.8	0.01	0.27		81	39	0.05	0		0.005		0.20	4.3	22			223	205
M	July 24/64	12600	15.3		10.2																				
M	July 30/64	9810	17.8	8.3	8.6	1.28	100	4.5	0.03	0.40	0.30	96	44	0.03	0.4		0.010		0.20	3.9	30			50	245
M	Aug. 6/64	8150	18.1	8.3	9.6	0.96	99	6.7				90	41								32			35	232
M	Aug. 19/64	7960	17.6	8.3	9.6	1.92		6.8	0.02	0.43	0.26	91	47	0.04	0.2		0.002		0.13	3.6	29			31	
M	Aug. 27/64	5950	13.6	8.3	9.9	0.96	100							0.05							31			15	
M	Sept. 11/64	6550	8.6	8.3	10.3	1.54	121					109	61								39			29	
S	Oct. 24/64	4310	4.6	8.0	12.2		140	6.2				128	48				0.003				135			11	
M	Feb. 19/65	3100		8.0	11.5		173	3.0	0.04	0.07	0.06	145	64	0.05	0.3	0.54	0.002	0.35	0.09	6.7	53	0.01	0	4	
M	March 8/65	3690		7.9		0.60	166	2.5	0.05	0.43	0.04	140	59	0.08	0.1	1.67	0.002		0.17	7.1	49	0.02	0	5	
M	May 4/65	11000	8.1	8.1	10.6	2.94	118	3.4				100	47			0	0.001	0.60	0.26		33			115	
M	June 4/65	41100	10.5	8.3	8.6	1.52	120	6.8	0.17	0.28	0.08	90	40	0.25	0	0.27	0.007	0.80	0.22	5.0	28	0.02	0	425	
S	July 8/65	35500		8.3			130	6.8	0.06	0.24	0.25	92	32	0.15	0	0.23	0.006	0.52	0.25	6.1	27			230	
S	July 15/65	39000	16.1	8.3	11.5	3.20	130	6.8	0.08	0.17	0.20	85	43	0.22	0.1	0	0.008		0.17	6.4	27			218	
S	Aug. 4/65	21800	20.8	8.3	9.1	0	123	6.8				92	36			0	0.003		0.28		22			102	
M	Aug. 12/65	21300	19.8	8.5												0.11	0.006	0.08				0.06	0.003	105	

APPENDIX I (continued)

Station II.

Site	Date	Flow cfs	Temp. C°	pH	D.O. ppm	B.O.D. ppm	Alk. ppm	Cl ppm	Cr ppm	Cu ppm	F ppm	Hardness ppm		Fe ppm	Mn ppm	NH ₃ ppm	NO ₂ ppm	NO ₃ ppm	PO ₄ ppm	Si ppm	SO ₄ ppm	Phenols ppm	A.B.S. ppm	Turb. Jackson units	Cond. mmhos
												Ca	Mg												
M	June 4/64	19700	14.9	8.3	9.9	1.28																			268
S	June 16/64	34500	12.0		9.6	2.13	101	6.8				80	30						0.10	3.9	22			600	188
S	June 24/64	34200	14.0	8.3	8.6	0.64	112	6.8				90	32								23			245	206
M	July 3/64	16600	17.1	8.3	8.0		128	6.5				100	50								31			49	260
M	July 13/64	23100	18.0	8.3	8.3	0.64																			210
M	July 24/64	12600	15.6		9.3	0.48	108	6.8				89	41								26			79	212
M	July 30/64	9810	17.7	8.3	8.6	1.60	119	6.8				94	48								31			46	248
M	Aug. 6/64	8150	16.4	8.3	8.6	0.64	110	6.7				84	46								30			40	232
M	Aug. 14/64	7960	17.9	8.3	8.3	0.32		6.8				90	33								43			33	
M	Aug. 27/64	5950	13.8	8.3	9.0	0.96	100						0.05								47			29	205
M	Sept. 11/64	6550	8.8	8.3	10.7	1.25	129	6.8				115	45								47			28	222
S	Oct. 24/64	4310	5.0	8.0	12.5	2.46	140	6.8	0.06	0.37	0.21	123	58	0.03	0		0.005	0.15	0.22	5.3	51			11	280
S	Nov. 6/64	3420	2.3	8.2	14.0	2.36	155	2.3	0.05	0.55		130	55	0.08	0.15		0.001	0.10	0.33	5.4				7	209
S	Jan. 13/65	2160	0.5	8.0	10.6	3.00	199	3.0	0.06	0.33	0.21	166	68	0.62	0.10	0.68	0.002	0.90	0.26	7.8	75	0.048	0.022	7	
S	April 15/65	18300	0.1	7.5	11.7	7.88	81	4.0	0.14	0.37	0.17	51	29	0.63	0.25	0.90	0.010	1.16	0.79	5.6	18			84	
M	May 4/65	11000	8.2	7.6	8.8	1.12	123	4.0				89	46			0.52			0.32		37				
S	May 19/65	9200	10.5	8.3	8.5		152	4.5	0.11	0.25	0.13	122	48	0.25	0.30	0.15	0.008		0.17	4.5	39	0.128	0.015	35	
S	July 2/65	55500	14.1	8.3	10.2	0.70	118	9.1	0.14	0.47	0.25	92	30	0.97	0	0	0.012	0.07	0.23	7.7	38			500	
N	July 19/65	29600	16.9	8.3	10.4	1.44	133	6.8				80	50			0	0.003		0.17		26	0	0	138	
S	July 19/65	29600	16.8	8.3	10.2	1.28	131	6.8				90	40			0	0.006		0.23		22	0.003	0.004	150	
N	Aug. 12/65	21300	20.1	8.5			115	6.8	0.03	0.05	0.30	86	32	0.07	0.05	0.07	0.004		0.18	3.7	21	0.083	0.005	103	
S	Aug. 12/65	21300	20.0	8.5			114	6.8	0.04	0.08	0.30	93	39	0.07	0.10	0.20	0.003		0.11	4.1	22	0.115	0.010	84	

APPENDIX I (continued)

Station III.																									
Site	Date	Flow cfs	Temp. C°	pH	D.O. ppm	B.O.D. ppm	Alk. ppm	Cl ppm	Cr ppm	Cu ppm	F ppm	Hardness ppm		Fe ppm	Mn ppm	NH ₃ ppm	NO ₂ ppm	NO ₃ ppm	PO ₄ ppm	Si ppm	SO ₄ ppm	Phenols ppm	A.B.S. ppm	Turb. Jackson units	Cond. mmhos
M	June 2/64	7140	14.9	8.3	9.8	1.92	181	4.0		0.15		111	55	0.05	0				0.50	8.6					270
M	July 3/64	16600	17.6	8.3	8.6	1.28	111	9.0				94	36								30				266
M	July 13/64	23100	17.9	8.3	8.2	0.54																			210
M	July 24/64	12600	15.6		9.6	1.28	111	6.8				90	34								27			72	230
M	July 30/64	9810	17.9	8.3	9.0	1.28	120	6.0				97	46								31			45	248
M	Aug. 6/64	8150	16.4	8.3	9.0	0.96	116	9.0				90	50								39			40	232
M	Aug. 14/64	7960	17.9	8.3	9.4	1.43		4.5				90	42								29			31	232
M	Aug. 27/64	5950	13.8	8.3	9.6	1.28	105							0.05							71			35	221
M	Sept. 11/64	6550	8.9	8.4	10.8		131					112	40											38	222
N	May 4/65	11000	8.2	8.3	7.4		130	4.5				95	40			0.38	0.003		0.28		29			73	
S	May 4/65	11000	8.5		9.9	8.30	135	6.8				92	48			1.80	0.020		1.92		48			75	
N	July 19/65	29600	16.9	8.4	10.4	2.40	128	6.8				92	36			0	0.008		0.21		23	0.018	0	150	
S	July 19/65	29600	16.9	8.2	10.2	9.92	135	9.1				100	45			0.91	0.027	0.80	1.81		42	0.037	0.164	95	
N	Aug. 12/65	21300	20.0	8.4			128	9.1	0.05	0.21	0.25	93	39	0.21	0.05	0.14	0.006		0.22	3.9	23	0.170	0	98	
S	Aug. 12/65	21300	20.0	8.3			120	9.1	0.05	0.10	0.30	93	37	0.07		0.77	0.007		0.67	3.9	28	0.142	0.054	80	

APPENDIX I (continued)

		Station IV.																							
Site	Date	Flow cfs	Temp. C°	pH	D.O. ppm	B.O.D. ppm	Alk. ppm	Cl ppm	Cr ppm	Cu ppm	F ppm	Hardness ppm		Fe ppm	Mn ppm	NH ₃ ppm	NO ₂ ppm	NO ₃ ppm	PO ₄ ppm	Si ppm	SO ₄ ppm	Phenols ppm	A.B.S. ppm	Turb. Jackson units	Cond. mmhos
												Ca	Mg												
M	May 29/64	6440	12.3	8.2	9.7	4.27	130														29				270
M	July 3/64	16600	17.9	8.3	8.0	1.28	126	6.5				102	48								33			92	280
M	July 24/64	12600	15.8		9.6	0.80	117	5.7				93	37								27			75	244
M	July 30/64	9810	17.9	8.3	8.6	1.60	130	9.2				98	42								37			51	265
M	Aug. 6/64	8150	18.9	8.3	8.3	0.32		4.5				87	51								28			41	232
M	Aug. 14/64	7960	17.8	8.2	9.3	1.92		5.0				87	46								30			36	237
M	Aug. 27/64	5950	13.9	8.3	10.2	1.60	105						0.05								36			20	221
N	May 4/65	11000	8.3	8.0	9.7	1.44	130	3.4				90	40			0.15	0.010		0.45		29			87	
S	May 4/65	11000	8.5		6.7	0.93	129	6.8				92	51			0.90	0.029		0.55		33			91	
N	June 4/65	41100	11.0	8.3	8.6	1.70	130	4.5	0.11	0.28	0.08	85	45	0.22	0	0.27	0.007	0.95	0.22	5.0	28	0.047	0.020	550	
S	June 4/65	41100	11.0	7.7	7.1	2.56	118	4.5	0.18	0.18	0	90	45	0.17	0	0.28	0.008		0.19	5.0	33	0.053	0.013	500	
N	July 19/65	29600	17.0	8.3			133	6.8				92	43			0	0.006		0.18		26	0	0	147	
S	July 19/65	29600	17.0	8.2			130	6.8				92	40			0.22	0.007		0.35		27	0	0.013	125	
N	Aug. 12/65	21300	20.0	8.3			120	6.8	0.05	0.18	0.40	93	34	0.06	0.10	0.10	0.004		0.15	3.9	22	0.042	0	90	
S	Aug. 12/65	21300	20.0	8.4			128	6.8	0.06	0.11	0.25	92	38	0.06	0.10	0.59	0.008		0.37	4.2	24	0.135	0.030	76	

Station V.																										
Site	Date	Flow cfs	Temp. C°	pH	D.O. ppm	B.O.D. ppm	Alk. ppm	Cl ppm	Cr ppm	Cu ppm	F ppm	Hardness ppm		Fe ppm	Mn ppm	NH ₃ ppm	NO ₂ ppm	NO ₃ ppm	PO ₄ ppm	Si ppm	SO ₄ ppm	Phenols ppm	A.B.S. ppm	Turb. Jackson units	Cond. mmhos	
M	June 4/64	19700	15.1	8.3	9.8	1.60	165	4.0		0.10	0.15	110	46	0.17					0.25	5.9	34				275	270
S	June 16/64	34500	12.3	8.4	9.6	6.93	104	9.5				85	40	0.05					0.10	4.0	28				575	213
S	June 24/64	34200	14.2	8.3	8.3	7.08	110	9.1	0.04	0.38	0.20	90	40	0.10	0.24		0.200		0.25	6.3	26				255	230
M	July 3/64	16600	17.5	8.3	9.0	1.92	127	6.8				101	47								30				74	282
M	July 13/64	23100	18.0	8.3	8.3	0.64	108	7.0	0.02	0.26		85	35	0.02	0.20		0.003		0.10	4.6	18				230	210
M	July 24/64	12600	15.6		9.6	1.13	122	4.5				93	44								28				73	230
M	July 30/64	9810	17.9	8.3	8.0	0.64	110	9.1	0.04	0.25	0.10	90	53	0.05	0.20		0.010		0.15	4.6	32				52	268
M	Aug. 6/64	8150	16.5	8.3				4.5				87	50								29				34	230
M	Aug. 14/64	7960	17.8	8.2	9.6	2.24		6.8	0.03	0.38	0.10	96	43	0.02	0.15		0.013		0.22	1.8	34				32	230
M	Aug. 28/64	5720	14.1	8.3	9.6	2.88	105							0.05							74				20	218
M	Sept. 11/64	6550	9.0	8.3	10.1	0.80	133	6.8				107	52								47				37	226
S	Oct. 24/64	4310	6.2	7.7	7.0	7.00	151	11.0	0.04	0.79	0.11	121	66	0.07	0.01		0.005	3.65	2.95	6.5	62				17	333
S	Nov. 6/64	3420	3.6	8.4	7.9	17.00	160	15.9	0.06	0.52		136	62	0.08	0.08		0.008	5.30	1.00	6.9	78				10	270
S	April 15/65	18300	0.5	7.7	8.3	8.50	80	5.0	0.50	0.03	0.26	52	37	0.40	0	1.22	0.013	1.74	0.36	6.0	28	0.090	0.012		320	
N	May 4/65	11000	8.5	8.3	10.1	2.78	130	3.4				87	41			0.22	0.003		0.35		28				73	
S	May 4/65	11000	8.5	8.1	9.0	4.90	120	5.0				87	58			0.46	0.002		0.46						85	
S	May 19/65	9200	11.1	7.7	6.1	6.10	142	6.8	0.12	0.29	0.20	110	64	0.23	0.35	0.15	0.004	5.70	0.30	4.5	47	0.028	0.036		42	
N	June 4/65	41100	11.2	8.3	7.5	0.20	120	6.8	0.17	0.22	0.10	85	40	0.23	0	0.27	0.007	0.30	0.18	4.8	28	0.008	0.012		500	
S	June 4/65	41100	11.2	8.2	6.2	3.84	115	6.8	0.18	0.32	0.10	90	42	0.24	0	0.32	0.009	1.50	0.19	5.0	32		0.044		475	
N	July 19/65	29600	17.1	8.2	9.4	1.76	130	6.8				95	37			0.19	0.007	0.05	0.15		27	0	0		152	
S	July 19/65	29600	17.1	8.3	9.8	7.84	128	6.8				97	36			0.43	0.010	0.35	0.25		28	0	0.010		125	
N	Aug. 12/65	21300	20.1	8.5			113	6.8	0.05	0.14	0.30	87	33	0.07	0.05	0.07	0.004		0.16	3.9	23	0.082	0.010		96	
S	Aug. 12/65	21300	20.1	8.4			122	6.8	0.04	0.08	0.25	95	35	0.03	0.10	1.22	0.012		0.19	4.1	27	0.135	0.034		85	

APPENDIX I (continued)

Site	Date	Flow cfs	Temp. C°	pH	D.O. ppm	B.O.D. ppm	Alk. ppm	Cl ppm	Cr ppm	Cu ppm	F ppm	Station VI. Hardness ppm		Fe ppm	Mn ppm	NH ₃ ppm	NO ₂ ppm	NO ₃ ppm	PO ₄ ppm	Si ppm	SO ₄ ppm	Phenols ppm	A.B.S. ppm	Turb. Jackson units	Cond. mmhos
												Ca	Mg												
	June 9/64	19800	15.5		6.3	2.24	109	9.5	0.02	0.09		93	42		0		0.005		0.18	5.0	31			305	239
	June 19/64	34000		8.3	8.8	1.92	113	6.8				90	35				0.009				25			205	
	Aug. 19/64	7590	18.8	8.4	8.6	2.67		11.3	0.01	0.04		84	51	0.04	0		0.003		0.18	3.9	34			23	231
	Sept. 15/64	5140	11.5		11.5	5.07	137	6.8	0.04	0.45	0.31	114	47	0.04	0		0.003		0.29	6.2	39			17	251
	Oct. 6/64	7030	8.3	8.2	10.7	3.30	130	6.8	0.07	0.63	0.01	105	55	0.05	0.01		0.003		0.70	5.6	50			23	205
	Nov. 6/64	3420	4.3	8.4	14.2		162	5.7	0.07	0.28		127	70	0.04	0.01		0.018	0.17	0.38	5.5	120			4	231
	April 23/65	8950	2.2	7.8	9.8	3.12	97	4.0	0.12	0.20	0.20	75	41	0.18	0	0.25	0.003	0.20	0.45	7.1	41			162	
	May 14/65	7700	12.2	8.2	7.4	1.04	120	4.5				115	60			0.13	0.005	0.40	0.27		72			17	
	July 12/65	65800	13.8		10.4	2.24	125	6.8	0.11	0.19	0.40	83	29	0.18	0	0	0.008	0.60	0.22	8.3	24	0.050	0.002	450	

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